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Elephants in Taita Taveta County Kenya: analysing and predicting the distribution

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Tiivistelmä/Referat – Abstract

African Savanna elephant (*Loxodonta africana)* is the largest terrestrial mammal. Due to its size, elephants consume large amount of food and water each day and thus modify the environment around them greatly. At the same time, they create living areas for other species. On the other hand, too large number of elephants in confined areas will eventually lead into the destruction of the environment. Humans and elephants have also a twofold relationship: elephants attract tourist but at the same time they can destroy crops, property or even kill humans.

The African elephant is thought to be a vulnerable specie that is in risk on becoming endangered in the near future due to the changing environment and the pressure from growing human populations. The population size has been long decreasing and for conservational work to be effective, knowledge about the suitable environments and the needs of the specie is needed. Species distribution modelling (SDM) uses computer algorithms to combine the environmental variables and species occurrence data. SDM can be used for example to predict suitable habitats for species and the method is regularly used in conservational work and is an important part of it.

The aim of this study is to increase the knowledge of elephant distribution patterns in Taita Taveta County in Kenya. In contrary to the overall trend of the elephant numbers, the population in Taita Taveta County has been growing. The changes in the population have been monitored from the 60's and data from three different years, 2005, 2008 and 2011, have been used in this study.

The study was divided in to three questions: (1) How elephants are distributed in the area in different years, (2) What environmental variables correlate with elephants in different years, and (3) Can the distribution of the elephants in the area be predicted? Different spatial analyzes and visual comparison was used to study the distribution of elephants in the county. Spearman Rho Rank correlation analyses was used to study the correlation of environmental variables and elephants and predicting of the elephant distribution was done using species distribution modelling method MaxEnt.

The results show that the elephant distribution changes each year, but certain key areas can be found in each year that elephants favor. The meaningful environmental variables change each year and between the protected areas in the county and the areas that are not protected. In protected areas the meaning of water sources is highlighted and in the other areas the meaning of human activities grows in importance. The variables used for this study did not create well performing predictions, and thus it would not be advisable to use them for predictions. Presumably, the environmental variables used are not enough to explain the distribution of elephants. Elephants can live in many different habitats and they move around a lot, which also further decrease the performance of the predictions

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Elephant, species distribution modelling, Taita Taveta County, Distribution

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Tiivistelmä/Referat – Abstract

Afrikan savanni norsu (*Loxodonta africana*) on suurin maalla elävä eläin. Koostaan johtuen norsut kuluttavat suuren määrän ravintoa sekä vettä päivittäin ja täten muokkaavat ympäristöään tehokkaasti ja luovat elinympäristöjä muille lajeille. Liian suuri määrä norsuja pienellä alueella johtaa kuitenkin nopeasti ympäristön tuhoutumiseen. Myös ihmisille norsuista on sekä hyötyä, että haittaa; norsut houkuttelevat turisteja, mutta samalla ne voivat tuhota viljelyksiä, omaisuutta tai jopa viedä ihmishenkiä.

Afrikan norsu on vaarantunut laji, joka on vaarassa muuttua uhanalaiseksi ympäristön muutoksen ja ihmisten luoman paineen takia. Lajin populaation koko on ollut pitkään laskussa ja lajin suojelemiseksi ymmärrys sen suosimista elinalueista ja vaatimuksista on tarpeen. Lajien levinneisyysmallintaminen (SDM) yhdistää ympäristömuuttujia ja lajien tunnettuja esiintymisalueita matemaattisin mallein. Levinneisyysmallintamisella voidaan esimerkiksi ennustaa lajeille suotuisia elinalueita ja niiden käyttö on tärkeä ja yleinen osa suojelutyötä.

Tämän työn tavoitteena on lisätä ymmärrystä Kenian Taita Tavetan maakunnan norsujen levinneisyydestä. Taita Tavetan maakunnassa norsujen määrä on viimeisien vuosien aikana ollut kasvussa yleisestä kehityssuunnasta poiketen. Populaation kokoa on alueella seurattu tarkasti 60-luvulta lähtien lentolaskentojen avulla ja tässä tutkimuksessa hyödynnetään kolmen vuoden, 2005, 2008 ja 2011, aineistoja.

Tavoitetta lähestyttiin kolmen kysymyksen avulla: (1) Miten norsut ovat levittäytyneet alueelle eri vuosina, (2) Minkä ympäristömuuttujien kanssa norsujen levinneisyys korreloi eri vuosina, ja (3) voiko alueen norsujen levinneisyyttä ennustaa. Lajin levinneisyyttä tarkasteltiin erilaisin spatiaalisin analyysein sekä visuaalisesti, korrelaatiota norsujen ja ympäristömuuttujien välillä selvitettiin Spearman Rho Rank korrelaatio analyysillä ja levinneisyyden ennustamiseen käytettiin lajien levinneisyysmallintamismenetelmää MaxEnt.

Tuloksien mukaan norsujen levinneisyys vaihtelee joka vuosi, mutta samat ydin alueet ovat tunnistettavissa kaikilta vuosilta. Norsuille merkittävät ympäristömuuttujat vaihtelevat hieman vuosittain ja etenkin suojeltujen ja suojelualueiden ulkopuolisten alueiden välillä. Suojelualueillakorostuvat veden merkitys ja muilla alueilla ihmisen toiminta. Tässä tutkimuksessa käytettyjen muuttujien avulla ei norsujen levinneisyyttä ole suositeltavaa ennustaa, sillä tulokset ovat heikkoja. Oletettavaa on, että käytetyt ympäristömuuttujat eivät ole riittäviä selittämään norsujen levinneisyyttä. Ennustamisen onnistumista heikentää myös esimerkiksi norsujen kyky elää monenlaisissa ympäristöissä ja suurilla alueilla.

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Elefantti, Taita Taveta County, Levinneisyys, lajinlevinneisys mallinnus,

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Table of contents

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

AUC	Area under the curve
EVI	Enhanced vegetation index
KWS	Kenya Wildlife Service
LC	Land cover
NDVI	Normalized difference vegetation index
SDM	Species distribution model

1. Introduction

African savanna elephant (*Loxodonta africana*) lives in the vast plains and savannas of Africa. Its distribution has decreased in time, and the specie has disappeared from the northern parts of Africa (IUCN/SSC, 2008). The overall population size has fluctuated over the years mostly due to ivory trade ((WWF - World Wide Fund for Nature, 2017). However, even as the overall population has been decreasing, some sub-populations have been growing. At the same time suitable living areas for elephants have been disappearing. These together have led to increasing densities of elephants in some areas and disappearance of the specie in others.

Elephant is the largest terrestrial mammal and has a large need for food and water. They tend to live in family groups and often gather together when circumstances are rough, for example in times of drought. Because of these, the elephant has a large impact on the environment it lives in. It moulds its environment by eating and stomping vegetation and thus acts as a keystone specie (Sukumar, 2003), creating environments for other species to live in.

In addition, elephant can be described as a flagship specie; protecting elephant and its surroundings also protects other species. Elephant is also an important specie for tourism, attracting people from all over the world (Brown, 1993). The importance of elephants towards the environment and tourism is certain.

At the same time, too much pressure from elephants towards the environment creates problems, since the vegetation can be destroyed by elephants as well (Bax & Sheldrick, 1963). Elephants and humans have also conflicts, which are causing harm for both (Røskaft, Larsen, & Mojaphoko, 2014). Human elephant conflicts are one of the most notable types of human wildlife conflicts in Africa.

Elephants' living areas are becoming more fragmented and smaller because of increasing human activities and population, climate change and environmental destruction by elephants themselves (UNEP, CITES, IUCN, TRAFFIC. 2013). These lead to more conflicts with humans, even more limited living areas and more competition for resources between elephants and other species.

Due to elephants' multifaceted role in natural environment as well as in human life and build up environments, it is important to understand where elephants live and why. Understanding is the key to preventing conflicts between humans and elephants, protecting elephants from changing climate and fragmenting environment and also protecting environment from the overuse of elephants. Protected areas are one of the best ways to accomplish these objectives and knowledge about suitable living areas is essential part of conservational actions.

Conservational work generally needs specific information about species; where they live, what are their threats, what do they prefer and how have the previous conservational actions affected. Often conservational work conflicts with other interests of people, especially in the case of elephants, and so knowledge is the key to accomplishing conservational objectives in spite of the limits brought upon the work by growing human populations, enlarging cities and the negative views on elephants for example.

Species distribution modelling can answer many of conservational work's needs concerning both animals and plants and also whole ecosystems and biotopes. Models have been used for example to specify the environmental constraints affecting certain species living areas (Wang et al., 2015) and to predict the occurrences in changing environments (Gaudreau, Perez, & Harati, 2018) and to assess the protection sites and their networks (Bosso et al., 2018). Species distribution modelling have also been used in elephant studies in the recent years, for example to study the meaning of environmental variables to elephants at different scales (De Knegt, 2011) and predicting areas most prone to poaching (Maingi, 2012).

Elephant studies have a long history and humans have always been fascinated with the large specie (Fritz, 2017). Physiology and behaviour have been probably the most studied themes in history and are still being searched, for example Hanks et al (1973) and Barbara McKnight (2015 have studied group composition and dynamics. Studies of the spatial patterns and behaviour started to emerge more from the sixties forward (Leuthold, 1977). Mainly the studies were carried out as field observations and later with radio collars and GPS-trackers, which are still used widely (de Knegt et al., 2011; McKnight, 2015). Species distribution models emerged to add analyses to study these data sets that were hard and slow to collect.

Even though the importance and interest towards the study of elephants have been long known, the focus has mainly been on small scale studies that use small data sets. Also, short-term studies have been the norm (Fritz, 2017). Kenya Wildlife Service has been collecting data about the animals in Tsavo-Mkomazi ecosystems by aerial counts from the sixties and possesses now a quite unique data set about elephants among other species (Ngene et al., 2017). The counts have been used mainly to follow the population's size and changes, however the data offers a possibility of utilizing species distribution models and year to year comparison that wouldn't be easy to do with only the data collected from field.

This study is based on the data from the Kenyan Wildlife Services' aerial count of elephants from three different years. The data is used to study elephant distribution and the reasons behind it in different years. Using data from multiple years can help gain important information about the changes and patterns in elephant distribution and for example to answer the question; can elephant distribution be predicted?

Taita Taveta County in southern Kenya covers most of the Tsavo-Mkomazi ecosystem and has one of the largest populations of elephants in Eastern Africa and the largest in Kenya. The population has been growing in size and the area has faced many of the challenges and benefits caused by elephants. Since the elephants in the county and the surrounding ecosystem have been monitored for a long time the possibilities of studying elephants are many.

Taita Taveta County also has a long history of elephant studies that grew more popular from the phenomenon in the sixties called the elephant problem at Tsavo (Glover, 1963) which awakened the researchers to study the elephants more in the area. Even though the data that have been collected from the area by Kenyan Wildlife services, the data hasn't been used in studies much. From the counts from different years the knowledge about the elephants in the area can be deepened and a longer-term approach utilized.

1.1. Study questions

The overall aim of this study is to have a deeper understanding about the spatial patterns of elephants and the reasons behind those patterns in Taita Taveta County. This thesis has three research questions:

1. How are the elephants distributed in the area?
2. What environmental and human influenced factors correspond best with the elephant densities in Taita Taveta County?
3. Can the elephant distribution in the area be successfully modelled using the best correlated environmental variables? Modelling tells more about the meaningfulness of the environmental variables used and about the elephant patterns and their yearly differences and similarities.

2. Background

2.1. African Savanna Elephant

African savanna elephant is the largest land mammal currently living. It is part of the eutherian order of mammals called proboscideans which are characterized by having a proboscis or a trunk (Brian R. Speer, Smith, & Kaitlin Maguire, 2010). The only surviving family of the order is Elephantidae which include for example the elephants that have two currently living species, the African elephant and the Asian elephant (*Elephas maximus*), and the extinct mammoth species.

African elephants grow to an average height of 3 metres and can weigh up to 6 tons (WWF - World Wide Fund for Nature, 2017). Size alone means that elephants need a lot of water and a lot of food to survive. Individuals can drink 200 litres of water per day and need an amount of food that is equivalent to 4% of their body weight, which can mean 200 kg of food per day. This means that much of their living space is characterized by water and food availability. Elephants are generalists, so they are not independent of any certain plant species (Bax & Sheldrick, 1963). In the dry seasons they are browsers, eating wooded plants and in the wet season they are grazers and mostly consume grasses (Skarpe, du Toit, & Moe, 2014).

Elephants live usually in family groups which are mainly constructed of differently aged females. Bulls tend to live alone once they are mature, but bull groups and mixed groups are also quite common. When circumstances are harsh, elephants tend to gather more and can even form herds of over 100 individuals. The gathering is the result of elephants traveling to the same limited areas that have water and food stocks during even the dry seasons (Leuthold, 1976).

Elephants are thus a massive constraint for environment and it only increases when the densities grow. Although they need a lot from the environment they are also invaluable for other species. That is, elephants act as a keystone specie by changing the environment they live in. Keystone specie is a specie that modifies it's living surroundings and creates niches and suitable living space for other species that might not otherwise be able to live in the area (Mills, Soule & Doak, 1993; Sukumar, 2003). Keystone species can mould entire ecosystems and ecotypes, and for example savannahs wouldn't be the same without large grazers and browsers. Elephants can also be called a flagship specie for environmental conservation (Sukumar, 2003). Protecting elephants will protect many other species at the same time. Even though elephants aren't endangered yet, many much smaller and unknown species are. But protecting those species is hard in contrast to elephants which everyone knows about and are easier to feel sympathy for.

Too many elephants in one place will nevertheless lead to the destruction of the environment and its vegetation (Glover, 1963; Laws, 1970; Owen-Smith & Chafota, 2012). When the environment is destroyed the species living in the area, including elephants themselves are forced to move elsewhere. So even though the elephant might be very important to upkeeping of certain habitats and protecting other species, it is also one the greatest reasons for habitat loss in many areas.

Elephant's role to the humans is also twofold. Elephants' role in tourisms is great, the specie attracting tourist to the areas and bringing money and living to many of the people (Brown, 1993). The downside of the elephants from human perspective is their usage of the same resources that will drive the two sides to conflicts (Røskaft et al., 2014). Human-elephant conflicts are part of the human-wildlife conflicts problems that arise especially in many of the tropical areas were wildlife is plenty. Elephants can destroy crops, constructions and even take human lives. This has led to despising of the large specie in many areas and by many groups of people. Conservation of the species and other work concerning elephants can get hard if the people have negative thoughts toward the specie.

2.2. Species distribution in general

Species distribution is the area that the specie lives in. It can be divided into potential distribution and realistic distribution (*Ecology* 1992; *Ecology basics*2004). Where the former covers all the areas that could provide for the specie and the latter the areas where the specie truly lives in. Species distribution is affected by abiotic and biotic factors. Often the most restricting factor is climate, and historical climate changes are known to have affected species distributions (Pearson & Dawson, 2003). Other usual factors are habitat types, elevation, biotic interactions between species and water availability. Even though areas could cater for certain species many other hidden reasons might be keeping the specie out of the area. These include for example historical reasons, competing specie, distance or just chance or too little time.

Distribution can be inspected in many scales from a global aspect to very local. It depends on the specie and the study questions how large scale should be used and what does it tell about the animal or the environment. Different environmental variables affect the distribution depending on which scale is used for inspection. Scale is also affecting many other parts of species distribution studies (Storch, 2007; Levin, 1992) and should be taken into consideration more when working on species occurrence data and deriving other information from it. Working with a wrong scale for the situation can give out misleading results and for example rare species can seem to have larger distribution than common species.

Home range is the area in which the individual animal actually lives in and from which it gets all it needs concerning for example food, water and breeding sites (Dickinson & Koenig, 2017). Inside these home ranges animals can have specific nesting sites or territories. Home range describes the distribution of an individual or a group of animals from the same species. Home range selection depends on the niche and favoured habitat of the specie. Animals' home range won't cover the whole suitable area available but only the area the individual or group needs.

2.3. Elephant population, distribution and home range selections

The species in the order of the Proboscidea have covered at some point almost all the largest land masses excluding the smallest and furthest islands and Greenland (Sukumar, 2003). The historical distribution of our currently living elephant species have also been much broader, the African elephant's distribution covering the whole of Africa excluding only the Sahara Desert, some of the near East and even parts of Europe. At that time the overall population might have been up to 20 million (Chase et al, 2016). After that, the areas have decreased together with the population size and World Wide Fund for Nature (WWF, 2017) have estimated that the African elephant population might have had about 3 or 5 million individuals in the early 1900 century.

Nowadays the distribution of elephants is even smaller in area and more fragmented (figure 1.) than it was. Elephants occupy areas only in the sub-Saharan Africa and in the total population is thought to be around 400 000 (Chase et al., 2016). Largest sub-populations at the moment are found in Botswana, where the population is counted to be well over 100 000 individuals (Chase et al., 2016). The population has therefore been decreasing and is evidently keeping on getting smaller. The trend of the population decreases in the last ten years have been even as high as 8% loss per year and it's thought to stay similar in the future.

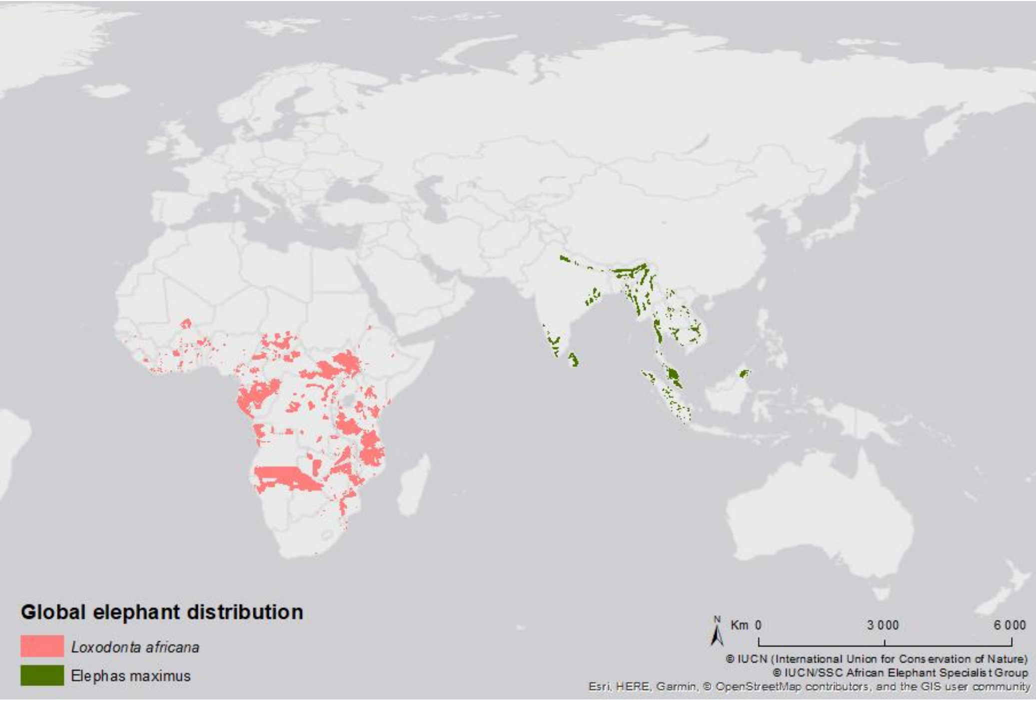

Figure 1 Current global elephant distribution. African elephant (IUCN/SSC, 2008) and Asian elephant (IUCN, 2008).

The Great elephant census (2015) have estimated that in the last ten years a third of the total population have been lost and in some areas the losses are even greater. For example, according to the census, Tanzania has probably lost even as much as 60% of its elephants in a much shorter time.

The decline of the elephant populations is thus a great issue. Historically it is harder to separate the reasons behind the population decreases, but different human caused reasons are thought to be the main cause (Chase et al., 2016; Lindsay, Chase, Landen, & Nowak, 2017; Sukumar, 2003). Nowadays it is easier to say that the ongoing trend is mainly caused by poaching and the poaching rates are on the rise (Lindsay et al., 2017; UNEP, CITES, IUCN, & TRAFFIC, 2013). Almost 90 elephants were found dead in August of 2018 close to a protection site in Botswana (Leithead, 2018). The tusks were removed from the elephants that were killed, thus implying that it's the work of poachers. What emphasis the problem even more, is that the elephants were all killed in time of only few weeks. Hence the African elephant is considered to be vulnerable and in risk of becoming endangered in the near future (Blanc, 2008; WWF - World Wide Fund for Nature, 2017).

Poachers are the main reasons for the decrease of elephant populations in many areas. In addition, other reasons are affecting the issue too and most of them are also caused by humans. One of them is the reduced size and fragmenting of the suitable living areas. Humans have many ways of affecting the environment and making it unsuitable for animals but also more natural reasons like climate change and elephants themselves can make the environment unliveable. Small areas cannot maintain large and resistant populations and growing human populations are separating the small areas from each other even more. The protected areas are thus vital for elephants and at the moment 80% of the elephants live inside these areas (Chase et al., 2016). However, also the protected areas are under a risk in some places and for example in Tanzania a hydroelectric plant is planned to be located inside a protected area, destroying much of the environment (WWF, 2018). Protected areas are also losing their benefits when the areas are isolated or the population size too great for the land area.

The fragmentation of suitable areas and further isolation of populations is thought to continue in the future. But even as the general trend of the population is to decrease in size, some subpopulations are actually growing. Population growth in small confined areas can often lead to very high densities of elephants. This too can have its own harmful consequences, since problems such as vegetation destruction, increased competition for resources and increased human-elephant conflicts are more prominent in high density areas. These problems could also cause further disadvantage to the elephants and cause the population sizes to drop eventually in the areas that now have growing populations.

As can be seen from the historical distribution of the Elephant, they are accustomed to living in very different environments. Their habitat choices can be very broad and changing, mostly the climate and water availability limiting the suitable areas. Their food choices are vast and instead of certain plants, usually only the amount available vegetation is of concern. Elephant doesn't have any natural predators that would limit its distribution and the only truly competitive and harmful specie for elephant is human. The current distribution is overall a combination of climatic and human caused reason, where hunting and poaching has been probably the main cause behind the large-scale population decrease and disappearance from many areas (Lindsay, Chase, Landen, & Nowak, 2017).

When the environment and resources are meeting the animals' needs, home range selection comes into question. Elephants' home range is usually quite large, the animals' large size being again one of the causes for that. They move around a lot, thus covering a bigger home range area than many other species. The home ranges of elephants vary a lot though and it can be as small as 240 km^2 or as large as 1 800 km^2 (Shannon et al., 2006). In comparison giraffe's (*Giraffa*) home range usually cover around 200 km^2 (McQualter et al., 2016) and leopards' (*Panthera pardus*) only around 30 km^2 (Mizutani & Jewell, 1998). Elephants don't have specific nesting sites or territories, but they might still have specific areas which they favour more.

Home ranges also vary along with season and are affected by the overall condition of the environment of the area. Smaller home range is enough if the resources of the area are plentiful whereas in areas less suitable elephants might need to travel more to find enough food and water (Leuthold & Sale, 1973). Seasonality affect the home range often conversely. When the resources are scarcer in the dry season elephants try to stay near the known water sources, so their home ranges would be smaller (McKnight, 2015). In the wet season even though the need to search for food is lessened the animals' drive to reproduce increases it's traveling so that more suitable partners can be found. Home ranges can also have some unsuitable areas in it and usually they are overlapping in case of elephants.

As can be seen, confining elephant's home range can be hard and because the home ranges are this large and varying, focusing on individual locations of elephants can be misleading when studying distribution.

2.4. Study area

Taita Taveta County borders define the study area for this research. The county is located in south-east Kenya. The total area is 17 083.9 km^2, from which protected national parks cover 11 100 km^2 (Taita Taveta County Government, 2015). The rest of the county area is occupied by ranches, estates and wild life sanctuaries and a small part is also covered by hilltop forests. Several towns are located in the Taita Taveta County area. The capital of the county is Wundanyi whereas the largest town is Voi. Population is at the moment already well over 250 000 and rapidly growing. Population density varies from 3 persons/km^2 to over 800 persons/km^2 (Taita Taveta County Government, 2015). Major highway splits the county in two, from North-west to South-east. New, broader highway is to be constructed near the current one. Similarly, to the highway, also a fenced railway crosses the area in the same direction.

Taita Taveta County is part of a Tsavo-Mkomazi ecosystem, which also include Mkomazi National Park in Tanzania, and the areas around Taita Taveta County in Kenya such as Chyulu Hills National Park. Climate in the ecosystem area is semi-arid with two rainy seasons, long rains in March to May and short rains from October to December (MoALF, 2016; Ngene et al., 2017). Although the two distinctive rainy seasons, rainfall varies greatly every year and between the areas inside the county as well (Leuthold & Sale, 1973). Annually rainfall vary from the lowlands' 440 mm to the highlands' 1900 mm. There is also variation in rainfall between east and western parts of the county, Tsavo East National Park getting less rain than Tsavo West (Leuthold & Sale, 1973). Average temperature in the area is 23°C, the hillsides being cooler and the lower zones hotter (MoALF, 2016).

Topography of the area can be divided into three zones (MoALF, 2016). Lower zone, which contains the vast plains of the area. Upper zone which includes Taita Hills and the highest peak in the area, Vuria climbing up to 2 228 metres. And the third zone that includes volcanic foothills. Most of the county area is covered within the lower zone, the rocky hills of upper zone appearing isolated around the area.

Few rivers run through Taita Taveta County, including the largest rivers Tsavo, Galana, Lumi and Voi rivers. Only few of the rivers have water all year the rest being ephemeral. Two lakes can also be found in the area, Lake Jipe and Challa. The most important spring in the area is Mzima springs, but also other smaller springs are located in the county area. Natural but seasonal waterholes also plot the area with permanent man-made waterholes in the protected areas.

Vegetation can be mostly described as savanna, which means that the densities of trees and shrubs vary creating open plain, shrub and woodland mosaic in the semi-arid environment. Denser and moister forests can be found in the hillsides and riverbanks (van Breugel et al., 2015). Over 30 different large animals live in the county area with many more small species, birds and invertebrates.

The county area has faced many problems with changing environment and climate. Some of these include soil degradation, drought and drying of rivers, deforestation and human-wildlife conflicts (MoALF, 2016). The area faces more pressure in the future from changing environment and growing population.

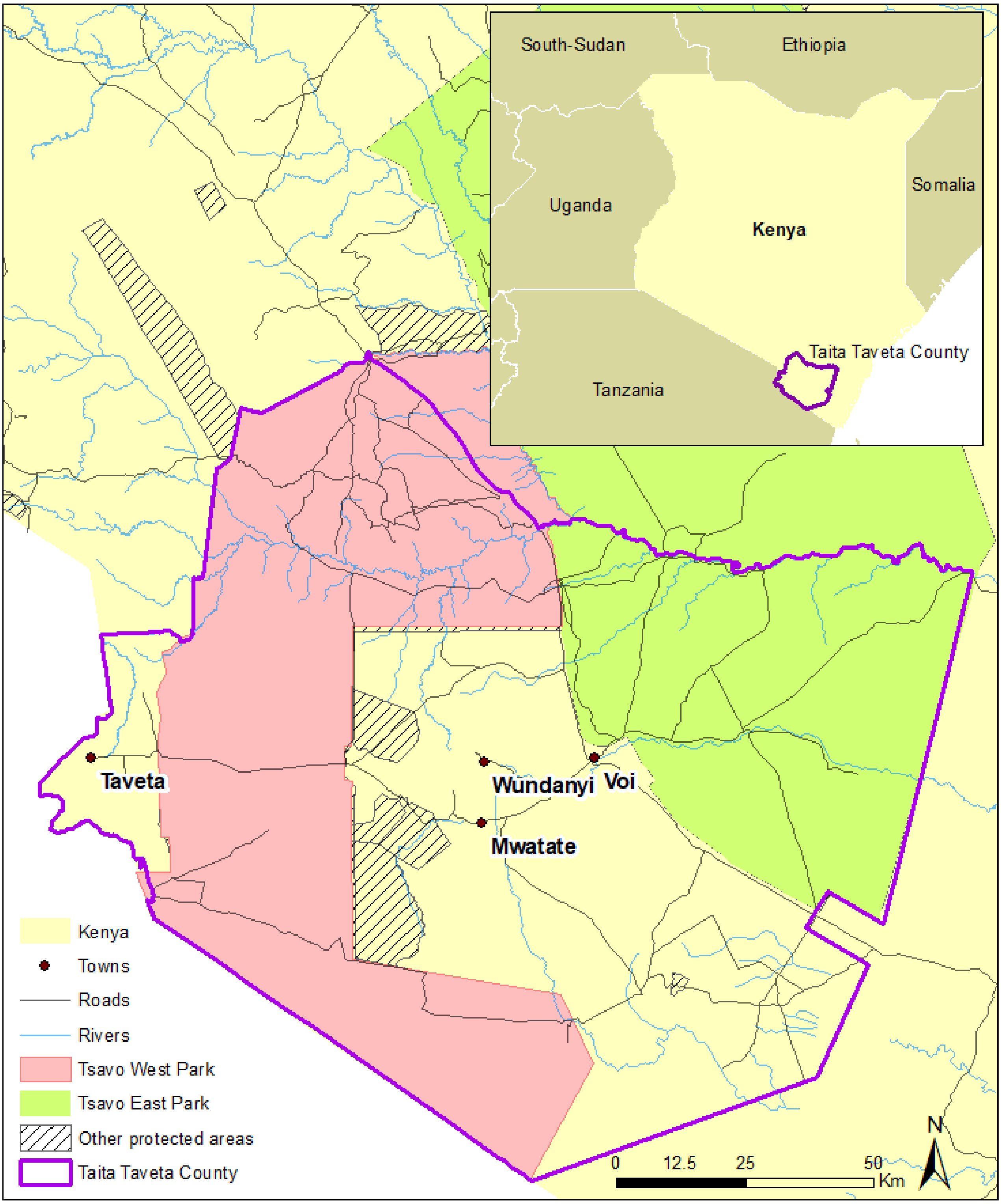

Figure 2. Map of Taita Taveta County.

Two national parks, Tsavo East and Tsavo West, cover over 60% of the study area. These parks continue outside of the county borders, bringing up the total area of the two parks to 40 000 km^2. These parks form the largest continuous protected area in Kenya. It is also the home area for the biggest Elephant population in Kenya, over 12 000 elephants (Ngene et al., 2017). That is estimated to cover even 2% of the total elephant population in Africa (Ngene et al., 2017). Few sanctuaries are also located in the county. Further in the text these areas covered by parks or sanctuaries are referenced to as protected areas.

2.5. Elephant population in Taita Taveta County

The elephant population in Taita Taveta County has been monitored closely from the 60's. Counts are made every few years.

The last count for the ecosystem was made in February 2017 and the total elephant count for the area was 12 866 individuals. In recent years the population has grown 4.9% per year (Ngene et al., 2017). There are a lot of baby elephants being born the past few years and so the population is thought to keep growing for now (*Personal communication,* 2018).

The population has been growing from the 80's. In some years the population size has decreased but overall direction of growth has been increasing.

In the 60's when the counts started the population size was about 10 000 elephants. It grew to 22 000 individuals in 1973 but radically dropped to around 6000 elephants in the next decade. From there on the population size has grown from the 6000 to 12 000 elephants.

Most of the elephants in the area live inside protected areas. The count of elephants living outside these areas has been changing each year but the average in recent years has been around 15% of the overall population.

There are also differences in the number of elephants living in Tsavo East and Tsavo West parks. Tsavo East has had more elephants from the 80's forwards. In 2017 in the West park there was 2833 individuals whereas the southern regions of East park had 6072 individuals (Ngene et al., 2017).

The home range sizes of elephants in Tsavo parks has been studied by for Leuthold and Sale (1973) and Leuthold (1977). It has been estimated that the home range sizes vary between females and males and between Tsavo East and Tsavo West. Average size for females is around 400 km^2 in West and 2 400 in East park. For males the respective sizes are 800 km^2 and 1 200 km^2. These differences between the sizes are the result of different environmental resources available in each park. Tsavo West has better resources and more rainfall than Tsavo East, which means that the elephants in there won't have to travel around so much in search of water and food (Leuthold & Sale, 1973).

Elephant-caused problems have also been noted in Taita Taveta County. The destruction of vegetation and environment by elephants has been noted already in the 60’s in the county (Glover, 1963) and is considered a large problem in the area and other areas as well (Laws, 1970; Skarpe et al., 2014). In the 1960’s there was also a phenomenon in the county linked to the destruction of vegetation called the Elephant problem at Tsavo (Glover, 1963). The problem was caused of the area having too many elephants than the environment can carry, and elephants were destroying its surroundings with eating too much. This problem hasn’t disappeared anywhere and some years depending on the drought the same situation has been re-emerging (Leuthold, 1977).

2.6. Distribution modelling

Species distribution modelling, SDM, includes a large set of computer-run algorithms used to predict species distribution based on environmental variables and the known location or absence data of species. The models can be made to fill an incomplete set of occurrence areas in the current time or to predict the total distribution for changing environments in the future.

Species distribution modelling is an important part of many fields, such as conservation work, ecology studies, invasive species control and many more. Understanding and predicting the distribution of species gives vital information that cannot be gathered with other methods. The field of SDM is rapidly developing and new methods and uses are being developed.

SDM has been used also when studying elephants. For example, in Tsavo national parks the areas prone to poaching (Maingi, Mukeka, Kyale, & Muasya, 2012) has been identified with SDM as has also been the elephants’ relationship with different environmental variables in different scales in Kruger national park (de Knegt et al., 2011).

Despite the unique capabilities of species distribution modelling, the methods have some notions about them that need to be taken into consideration. According to Phillips et al. (2005) to get valid information from the predictions the environmental variables have to be accurate to the time and space of the study area, the variables has to have importance to the animals and missing variables might be necessary to get reasonable results. Also, the predicted areas tend to be larger than the actual occurrence areas because the models cannot take into consideration some factors such as history, movement barriers or competition. Different models make different prediction areas and the selection of the model has to be given some thought.

3. Data and methods

3.1. Elephant data

Elephant data is from Kenyan Wildlife Services (KWS). The datasets have been collected in 2005, 2008 and 2011 as a part of global CITES-MIKE program which's aim is to monitor and prevent population decrease caused by illegal killings (Van Aarde & Ferreira, 2009). Data for all the years have been collected in the dry season, in late January or early February to keep the counts comparable. The population in the Tsavo-Mkomazi ecosystem has been monitored from the 60's and aerial counts are made every few years. The counts are made by trained personnel from an airplane with strict flight routes over the observed area (Omondi & Bitok, 2005). Every elephant and herd are marked and counted, and specifications are made with aerial photos when the herd was in a hard to observe location. Elephants located inside the Taita Taveta County have been extracted from the total data that covers the whole Tsavo-Mkomazi ecosystem area.

For the year 2005 animal count was made between the 27th and 31st January. Total of 10 397 elephants were counted for the whole ecosystem, from which 7 744 were located inside Taita Taveta County. Elephants were divided in to 784 herds. From these elephants 6 439 were located inside of the protected areas.

For the year 2008 animal count was made between 27th January and 2nd February. Total count of elephants in the ecosystem was 11 733. Elephants living in the Taita Taveta County counted 6 961 which was consisted of 627 herds. Of these animals 5 931 were located inside the protected areas.

For the year 2011 animal count was made between 7th and 12th February. In the whole ecosystem area, total of 12 573 elephants was counted. From these, 8 544 elephants were located in the Taita Taveta County and total of 927 herds was counted. Elephants found in the protected areas were counted to be 6 326 individuals.

Kernel density was counted for every year of the elephant data. Density was used to study the correlation between elephants and the environmental factors. For modelling, elephant locations were used. Elephant densities tell probably more about the species distribution and favoured areas than individual locations, because of elephants' home range size and behaviour and so it is used to study the correlations.

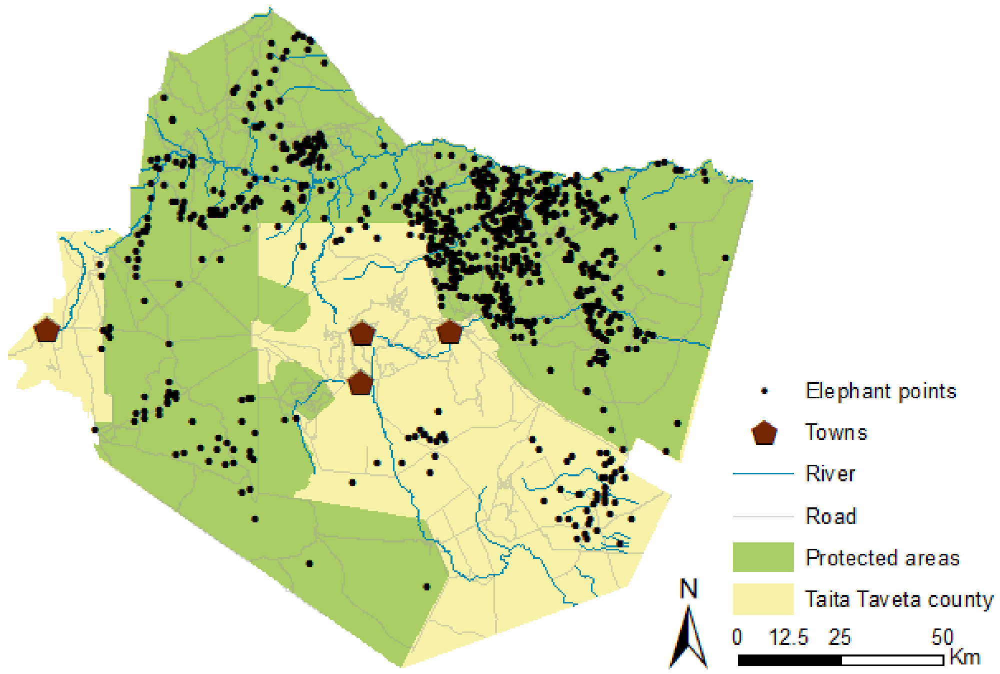

Figure 3. Aerial count of elephants from 2005. One elephant point represents either an individual elephant or a herd. Points counted 784, total number of elephants 7 744.

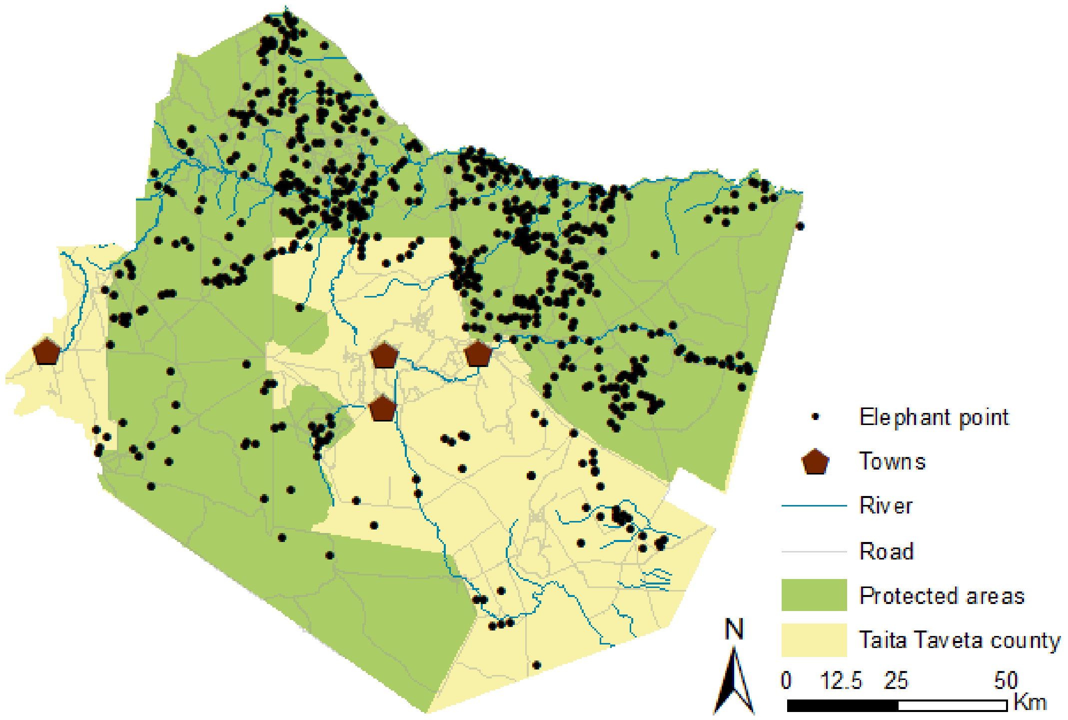

Figure 4. Aerial count of elephants from 2008. One elephant point represents either an individual elephant or a herd. Points counted 627, total number of elephants 6 961.

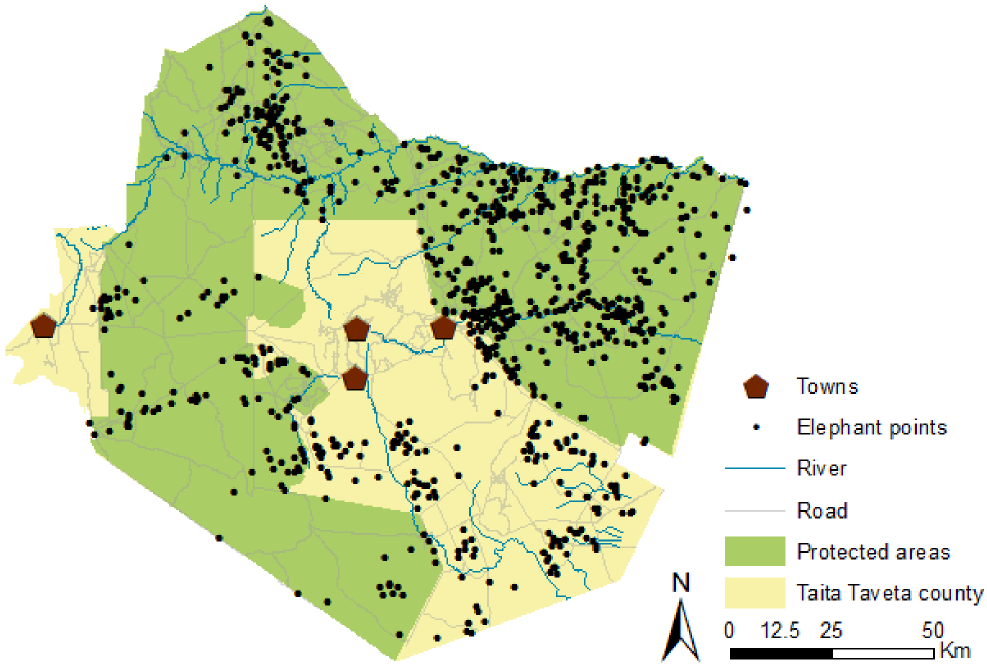

Figure 5. Aerial count of elephants from 2011. One elephant point represents either an individual elephant or a herd. Points counted 927, total number of elephants 8 544.

3.2. Environmental variables

For this study nine common environmental and human affected variables were chosen based on available data and literature (for example de Knegt et al., 2011; McKnight, 2015). Some variables that would have been justifiable to use were left out since the data weren't available easily or the data doesn't exist.

Variables chosen were slope and wetness index, land cover (LC), Normalized difference vegetation index (NDVI) and enhanced vegetation index (EVI), roads and buildings, water holes and rivers and protected areas. Slope was chosen instead of elevation since it describes the environment better and is more meaningful to elephants. Land cover, NDVI and EVI were chosen to represent the vegetation of the area.

Buildings and roads represent human impact in the area. For water sources rivers and water holes were chosen because they are the most important water sources in the area. Land cover, NDVI and EVI were available for each study year, the other variables were the same for all the study years.
Slope, wetness index, Land cover, NDVI and EVI were left as they were in raster format. The other variables were calculated a kernel density and a distance layer. The same cell size was given to all rasters created, it being 500 × 500 m.

Table 1. Environmental variables used in the study.

Variable	Description	Cell size (m)	Source:
Land cover		500	Land Cover Type Yearly L3 Global 500 m SIN Grid
NDVI		500	MOD13A1 MODIS/Terra Vegetation Indices 16-Day L3 Global 500m SIN Grid V006
EVI		500	MOD13A1 MODIS/Terra Vegetation Indices 16-Day L3 Global 500m SIN Grid V006
Slope	Slope based on DEM	500	JAXA
Rivers	River density and distance from the nearest river	500	-
Houses	House density and distance from the nearest house	500	Digitized from Google satellite imagery
Water Holes	Water hole density and distance from nearest water hole	500	Digitized from Google satellite imagery
Roads	Roads density and distance from nearest road	500	-
Protected areas	Distance from protected areas	500	-

NDVI = Normalized difference vegetation index, EVI = Enhanced vegetation index

A buffer of 10 km was calculated for the water wholes and rivers together, since many sources claim (de Knegt et al., 2011) that elephants tend to stay always a maximum of 10 km away from nearest water source and that 10 km is relatively close distance for elephants. Some variety to this distance can be found between some authors for example Ayeni (1975) claims that in the dry season this distance would be for most of the elephants 5 km whereas Glover (1963) considered the distance to be maximum of 15 km. Distance was calculated from the other areas to the created buffer zones. However, the distance layer of the buffer zones was left out of further analyses since almost all of the areas inside the county are within 10 kilometres from at least one possible water source.

Water Holes and houses were digitized from aerial photos. Part of it was done by Sakari Äärilä (Äärilä, 2017) previously and then it was updated to fit the whole county area for this study.

Some variables were considered for this study based on mentions in literature, but they were left out mainly due to unavailable data. These include canopy cover, which could be used to describe the shady areas that elephants are known to use (McKnight, 2015); Fences, which would be limiting elephant movements between areas; Rainfall, which indicates better food and water sources (Fritz et al. 2002); and cattle, which elephants are known to avoid (Ngene et al., 2017).

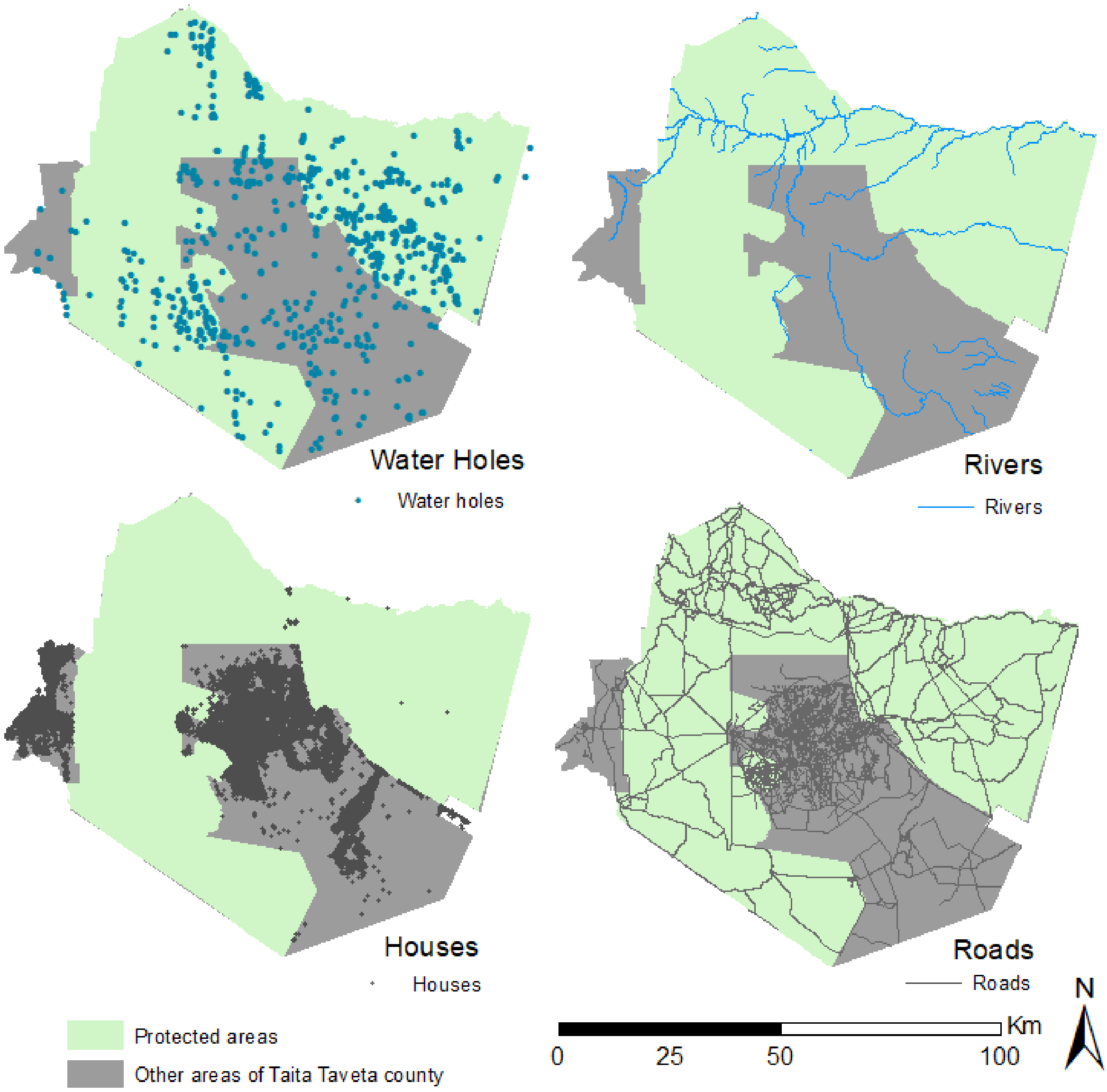

Figure 6 Water Holes, River, Houses and Roads in Taita Taveta County.

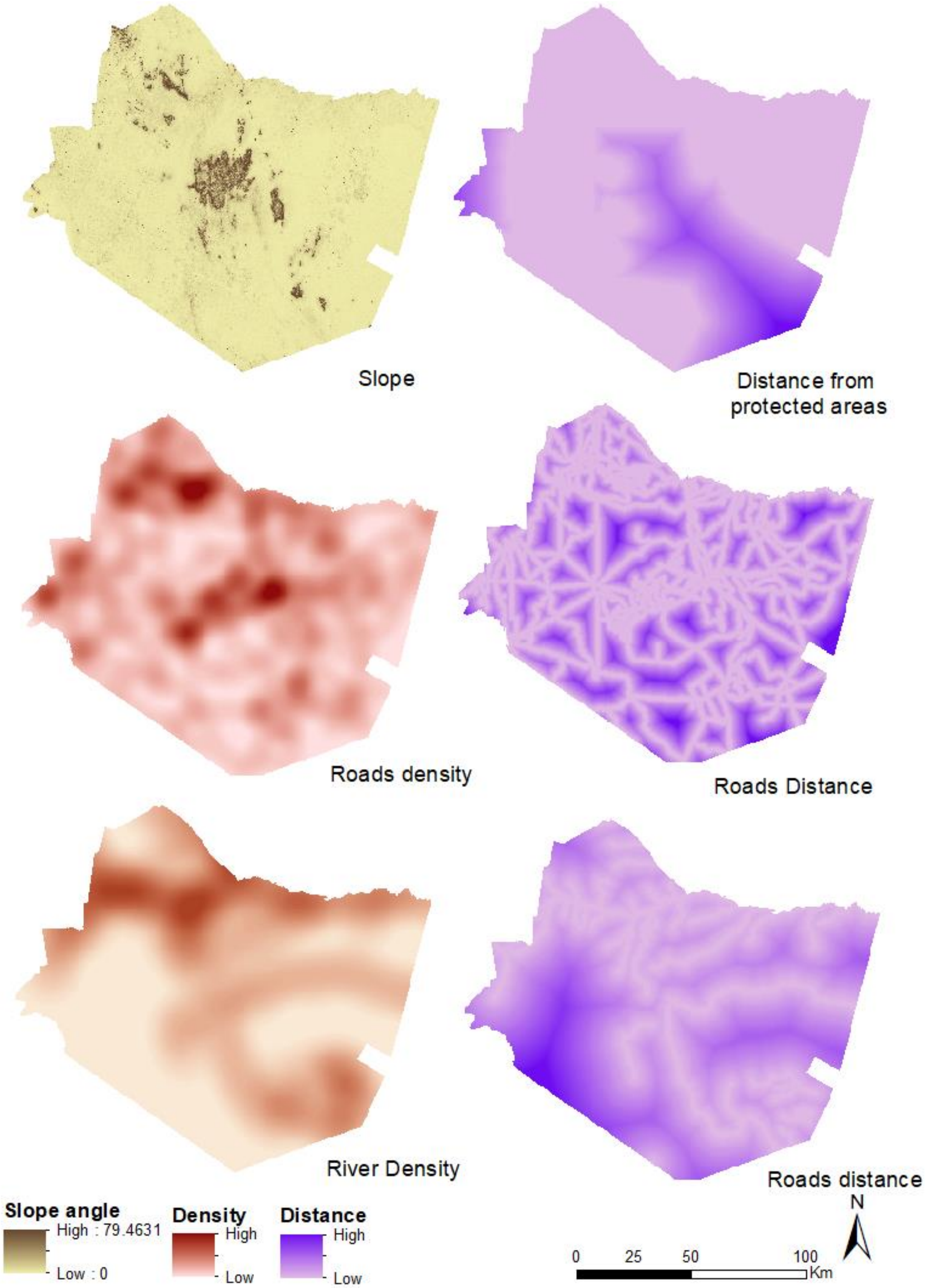

Figure 7.1. Environmental variables used in the study. Slope, Distance from protected areas and distance and density of roads and rivers in Taita Taveta County.

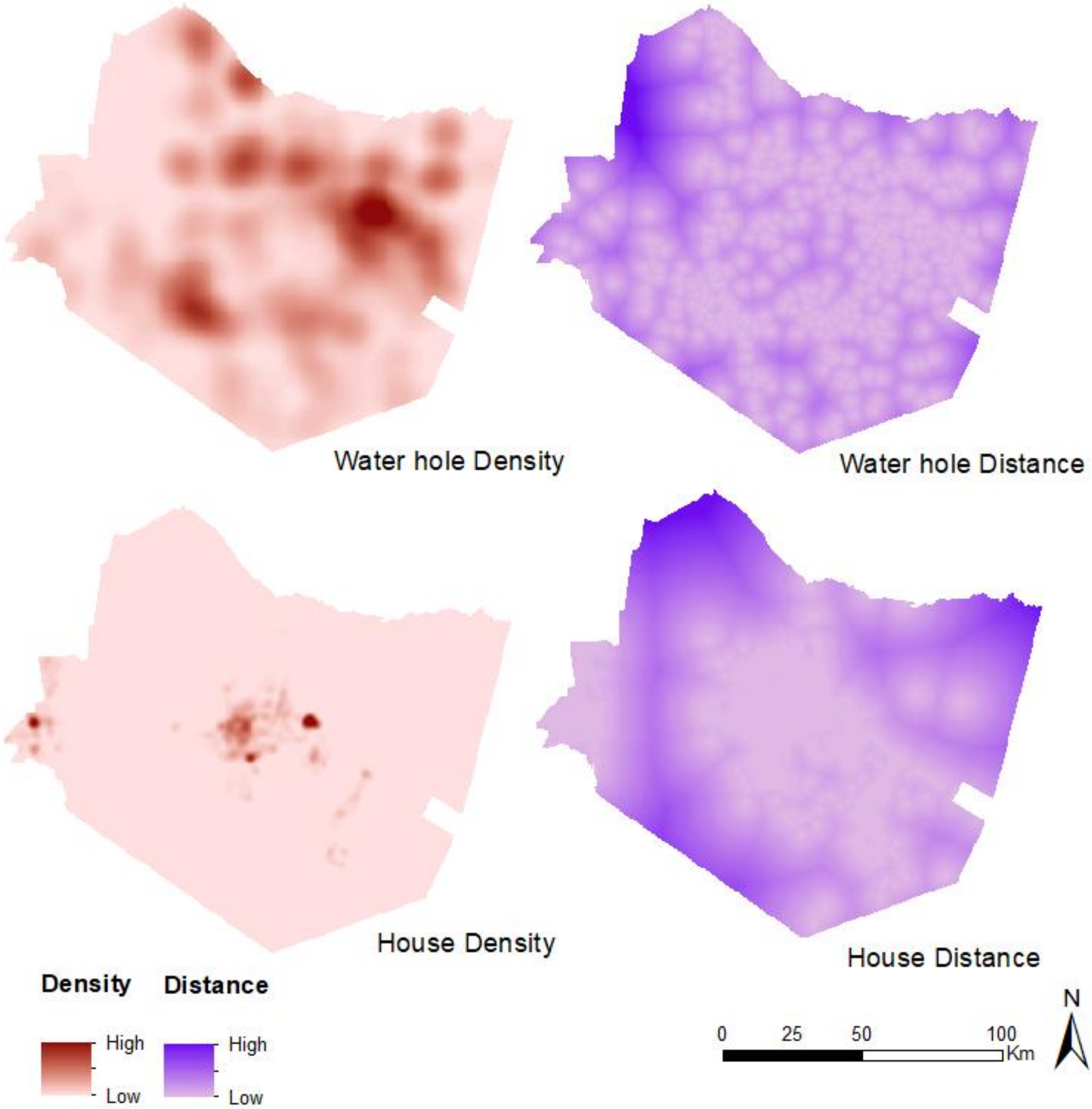

Figure 7.2. Environmental variables used in the study. Density and distance from water holes and houses.

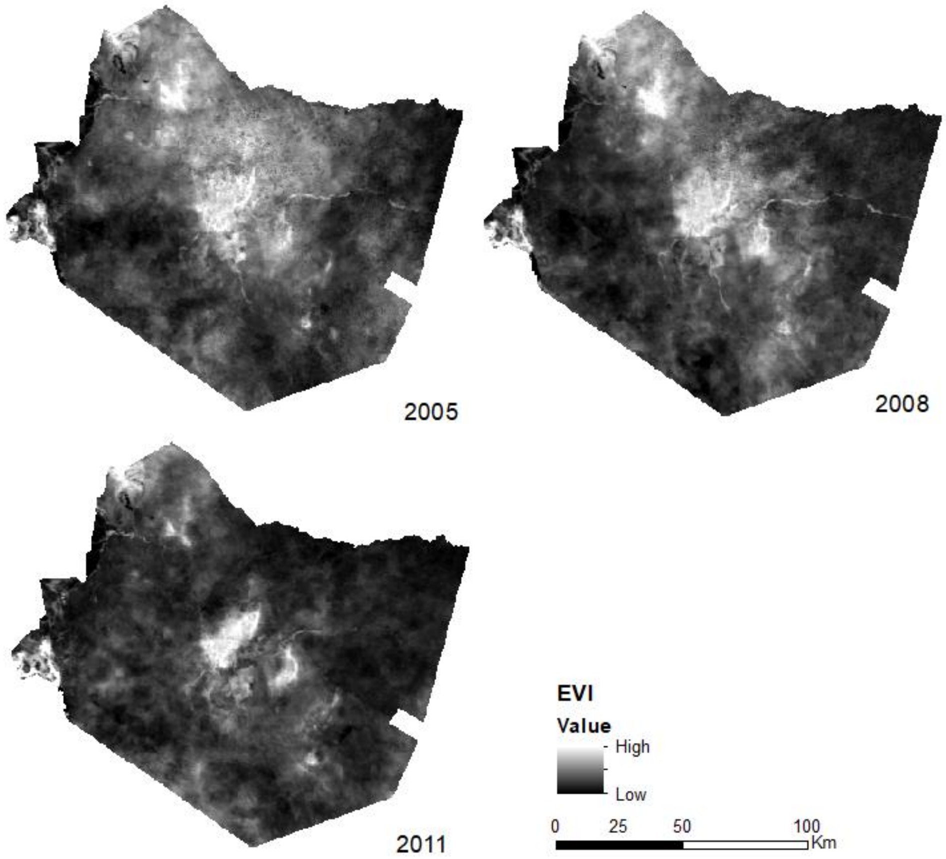

Figure 8. Enhanced vegetation index (EVI) in Taita Taveta County for 2005, 2008 and 2011.

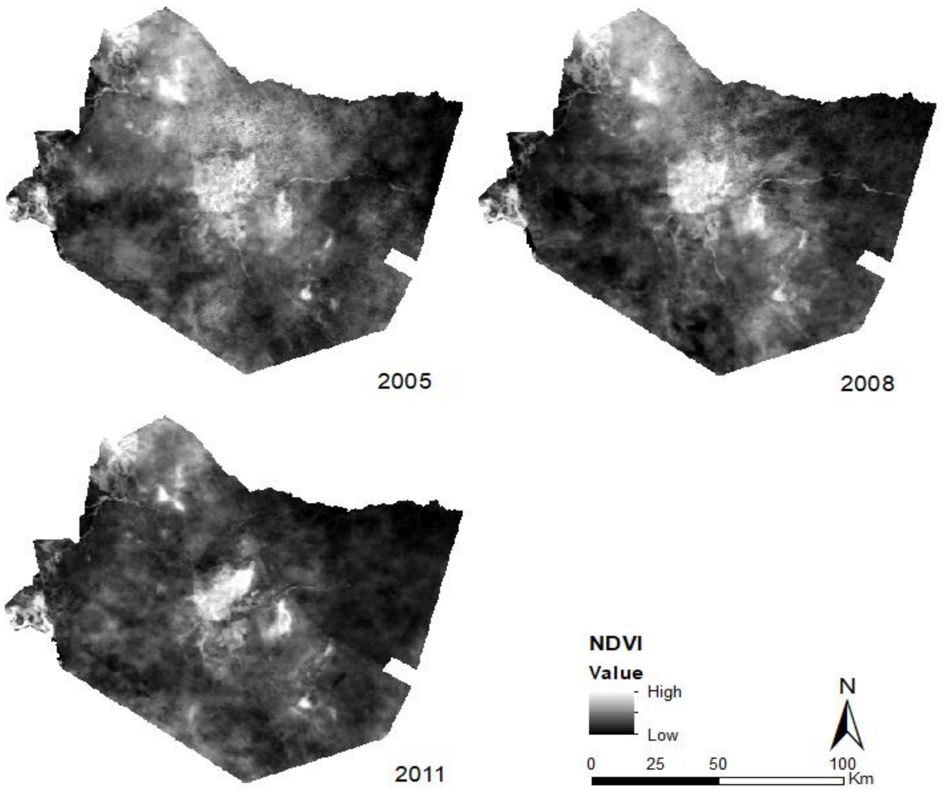

Figure 9. Normalized difference vegetation index (NDVI) in Taita Taveta County for 2005, 2008 and 2011.

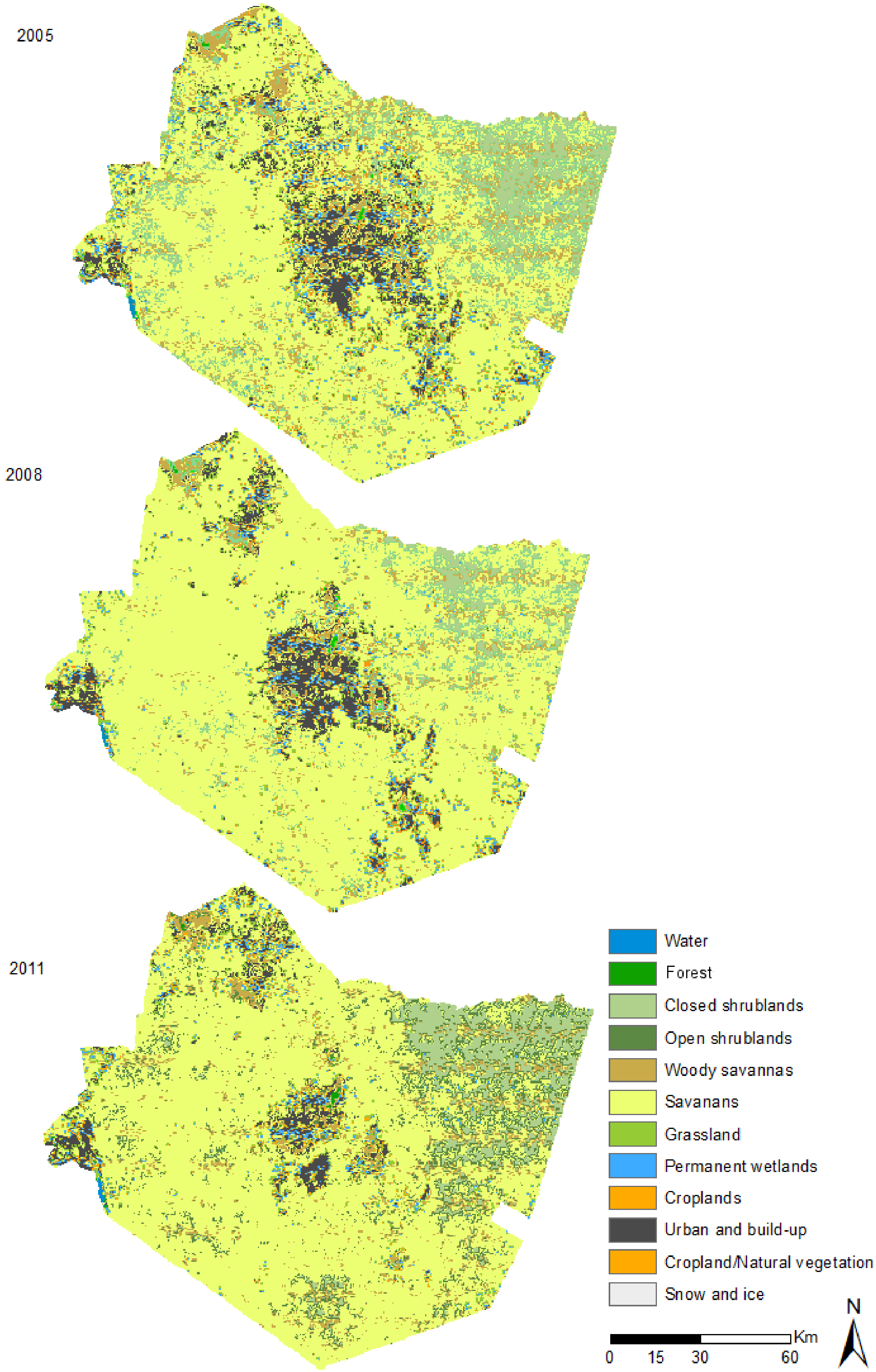

Figure 10. Land cover in Taita Taveta County for 2005, 2008 and 2011.

Table 2. Land cover classes' coverage each year as percentages of total area.

	2005	2008	2011
Water	0.0	0.0	0.0
Forests	0.1	0.1	0.1
Closed shrublands	7.1	2.2	4.9
Open shrubland	8.7	4.7	8.9
Woody savannas	7.2	5.1	9.4
Savannas	67.1	73.6	57.8
Grasslands	3.3	4.5	6.2
Permanent wetlands	1.5	2.1	3.2
Croplands	1.2	1.9	2.8
Urban and build-up	3.2	5.3	6.1

3.3. Elephant distribution pattern analyses

The patterns of elephant distribution in Taita Taveta County were studied with few spatial analyst tools in ArcMap.

Firstly, kernel density maps were produced for all of the study years and then compared to see how the years differ and how they are similar. Kernel density tool calculates density raster based on a feature layer (Esri, 2016b), in this case the elephant point data. Population field can be used to weigh some feature within the data, and the herd size was used for this purpose to better study the actual densities rather than just occurrence density.

Then, Directional Distribution analysis was run to calculate Standard Deviational Ellipses for each year to study the dispersion and direction of the elephants each year. This tool is used to study the trends in the data and the ellipses show the centre, direction and distribution of the studied feature (Esri, 2016a). This time also, the herd sizes were given as the value of the feature points to make a weighted standard deviational ellipse, to again, better study the actual distribution of the elephants and not just their occurrences.

ESRI's Spatial autocorrelation -tool was used to get information about the clustering tendencies of the elephant herds. The tool calculates Morans' *I* index, which indicates the weighted input features tendency to form clusters and it calculates also the z-score and p-value to indicate the statistical significance of the clustering (Esri, 2016c). Elephant herd size was used as the feature value and so the results indicate the clustering of differently sized herds.

Visual comparison of the elephant occurrence data was also done for each year. Herd sizes and distribution and the population sizes were also used to study the changes in the elephant data for each year.

3.4. Correlation analyses of the environmental variables and elephant data

To study the meaning of the environmental variables for elephants a correlation will be calculated using Spearman rho rank correlation. The correlation is calculated using elephant density layers for all years and all of the environmental variables. The correlation analysis will be carried out using 500 m x 500 m cells.

The correlations are calculated in three parts for each year. First for the whole county area and then separately for protected areas in the county and the areas outside of the protected areas. Protected areas differ a lot from the areas where human populations live and affect their surroundings and elephants are known to suffer harm from humans and their actions, so inspecting these two areas separately will presumably give more insight to the areal differences from elephant's perspective.

Meaning of the variables is also important to know for the modelling purposes. It is advised to only use variables that have importance to the specie in question and in the scale used (Phillips et al., 2006; Pearson et al., 2004). Using irrelevant variables would only disturb the analyses and probably lead to decreased performance of the results.

Land cover is tested separately since it is categorical data unlike the other variables. Different land cover types are tested with elephant occurrence data only. Calculations are made about how big percentages of elephant points each year are found in each land cover type. Herd sizes are not considered.

Based on the correlation analyses, the best correlated variables were picked to use in further analyses. Variables were picked for all three areas separately.

3.5. Elephant distribution modelling

For this study, maximum entropy modelling, or MaxEnt, was chosen to be used. It is a machine learning method that uses presence-only data and given set of environmental variables to make predictions of habitat suitability (Philips et al, 2006). The model uses the known locations of the species to assess the values of the environmental variables in each location and then defines the predicted distribution areas based on maximum entropy. The model can be run on a Maxent software that is free to be downloaded and used. Since the models are easy to run on the software and because the results are often thought to be good (Elith et al, 2006; Phillips et al., 2006; Hisz et al., 2008; Merow et al., 2013), the method was chosen to be used for this study.

For the evaluation of the predictions, area under the curve (AUC) was used. It is an often used evaluating method for SDMs that describes how well the models distinguishes presence and absence areas of the species. The AUC score is a number between 0 and 1, where 0 means that 100% of the predictions are wrong, 0.5 means that the predictions are as good as random and the score 1 would mean that 100% of the predictions are correct. The AUC is non-parametric and doesn't use thresholds, and so it evaluates not the exact values but if a random positive example is ranked higher than a random negative example (Philips et al., 2006).

For evaluation of the model a data set of specie's presence points are needed. The data sets for each year are thus divided randomly so that 70% of the data is used for training of the model and 30% for testing. Since data from multiple years are available for this study, models were also trained and tested with different year's data sets. Each year's data was used as a whole to train a model and then the model was projected to another year using the new year's environmental variables. The projected models were then tested with the year's data that the model was projected to.

Different environmental variable combinations were used in the models. Best correlated variables were chosen according to the correlation analysis and then also EVI and LC were added to be used in the models. The same three areas were also used for modelling and models were trained separately for the whole county, for the protected areas and for the areas outside of the protected areas.

To test the variables' meaning also in MaxEnt, all of the variables were used once to model the whole county area and Jackknife test were run. Jackknife test runs the model excluding each variable at a time and then with each variable as the only variable and calculates a total gain for each run. This way the variables that affect the predictions the most can be noticed, since their absence from the model will decrease the total gain of the run.

The performance of the model that uses all of the variables can be also compared to the models using only selected variables. Generally using the fewest possible number of variables to get the best possible performance is preferred and so to see if the chosen variables are achieving the same levels of performance than when using all of the variables, the comparison is needed. And as stated above, using variables that have no importance in the selected scale are usually sought out to be removed from further analyses.

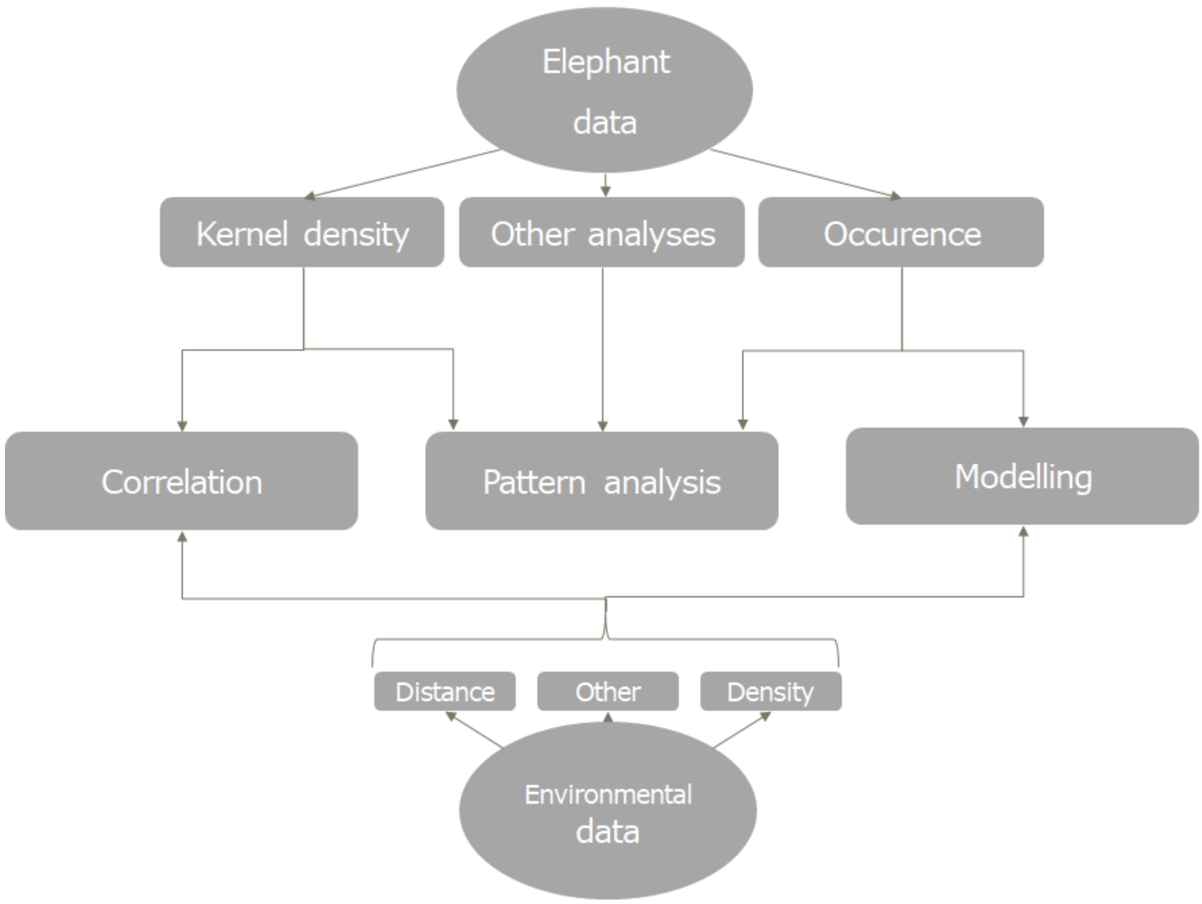

Figure 11 Flow chart of the modeling methods used in the thesis.

4. Results

4.1. Elephant distribution patterns in Taita Taveta County

Since elephants move a lot and exact locations won't necessarily be of great importance, the density of elephants would offer more useful information. With density calculations the herd sizes can also be considered and the areas that are most favoured or most suitable can be noticed.

Kernel density maps of the elephant data show how the elephants are clustered each year. The scale of values for each map change, but nevertheless the maps show the hotspots and differences between the years well enough.

The highest density changed between years. For the year 2005 it was 2.6 elephants/500 m^2, for 2008 it was 1.7 and for 2011 2.1. The maximum density is higher in the year 2005 of all the years, and so the elephant could be thought to be located closer to each other and in a smaller area than in other years.

The clusters are also somewhat distributed differently in each year. For all of the years clustering is happening in the north-east part of the county, in the Tsavo East National Park. But for the year 2005 the hotspots are much less dispersed. In 2008 the hotspots seem to cover larger area than in the previous year but still be located in a near distance. The year 2011 on the other hand has smaller hot spots but they are dispersed wider than in the two other years.

Elephant data was also analysed with standard deviational ellipses which give information about the centrality, direction and dispersion of the data. The ellipses are showed in Figure 13.

As can be seen from the ellipses, they change for each year. The year 2005 and 2008 quite similar ellipses, but they are directed bit differently and for the year 2005 the ellipse is a bit smaller. As for the year 2001, the ellipse is much rounder and larger than for the two other years, meaning that the elephants are distributed more widely and around the area. What all the years have in common is the location of the ellipse central. The biggest densities of elephants thus being in the north-east parts of county, in Tsavo East National Park area.

Morans' *I* index from the different years varies, indicating that the year 2011 has a slight clustering of larger herds, 2008 for small herds and the year 2005 having random distribution of different sized herds. Only the clustering patterns from the years 2005 and 2011 are statistically significant, and that the year's slight clustering could be an outcome of spatial randomness. Overall the Morans' *I* index indicates that there is hardly any clustering concerning the herd sizes.

Table 3. Moran's *I* index of elephant herd sizes for 2005, 2008 and 2011 in Taita Taveta County.

	Moran's *I*	z-score	p-value
2005	0.031	5.38	0.00
2008	-0.32	-1.04	0.29
2011	0.32	2.8	0.004

Visual comparison of the elephant data also demonstrates the differences for each year well. What cannot be seen from these maps is that the points of elephants aren't representing only one elephant, but they could be many. These are only the locations of elephant occurrence.

In spite of the fact that, it can be seen that in the year 2005 the clustering in the north-east parts of the county seems to be stronger than in the other years. In the year 2008 the elephants and herds seem to be evenly distributed around the northern parts of the county and for the 2011 more elephants seems to locate around the southern parts. Also, the year 2011 seem to have more elephants outside of the park areas.

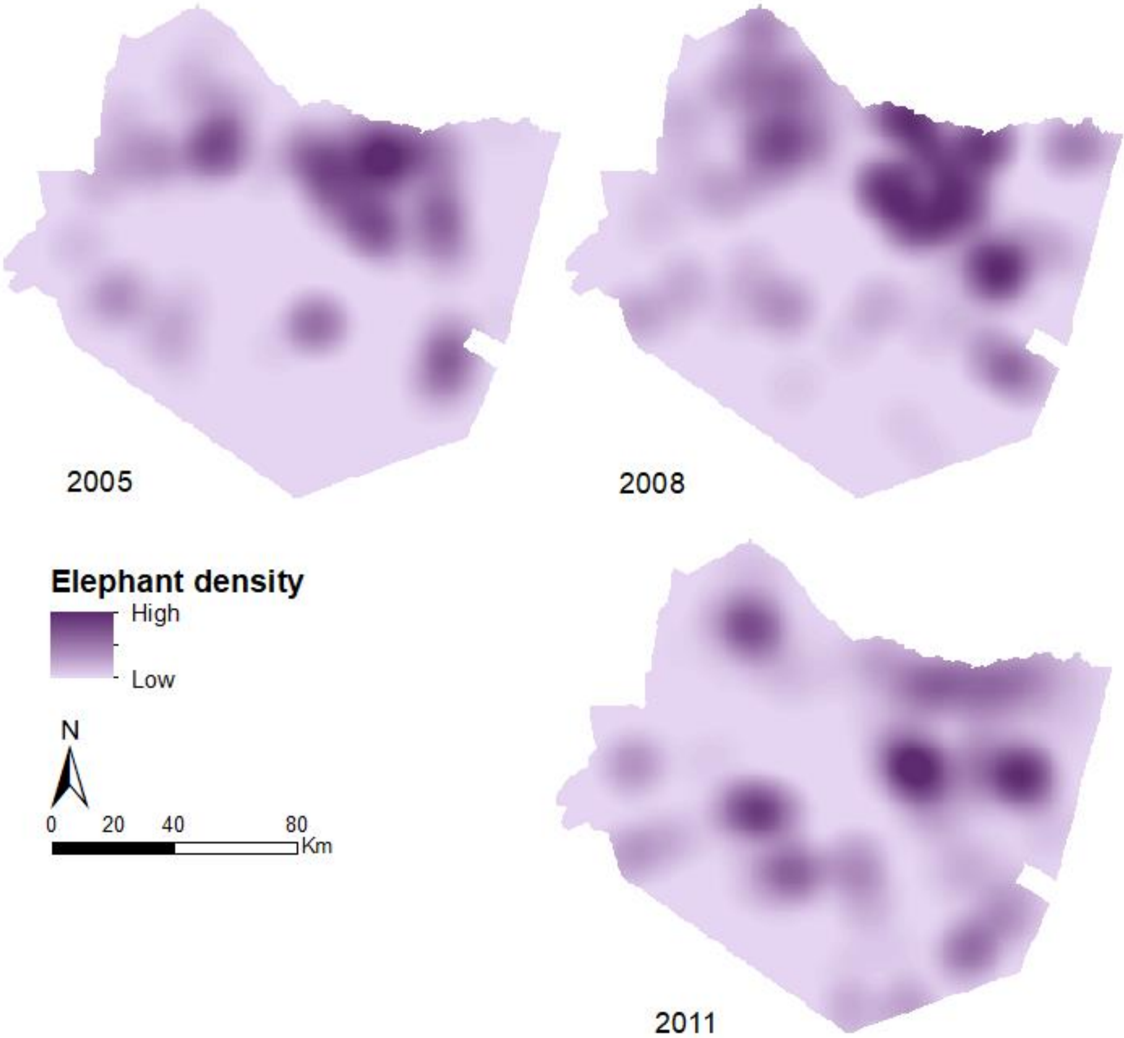

Figure 12 Elephant kernel density map for 2005, 2008 and 2011. Weighted with herd size.

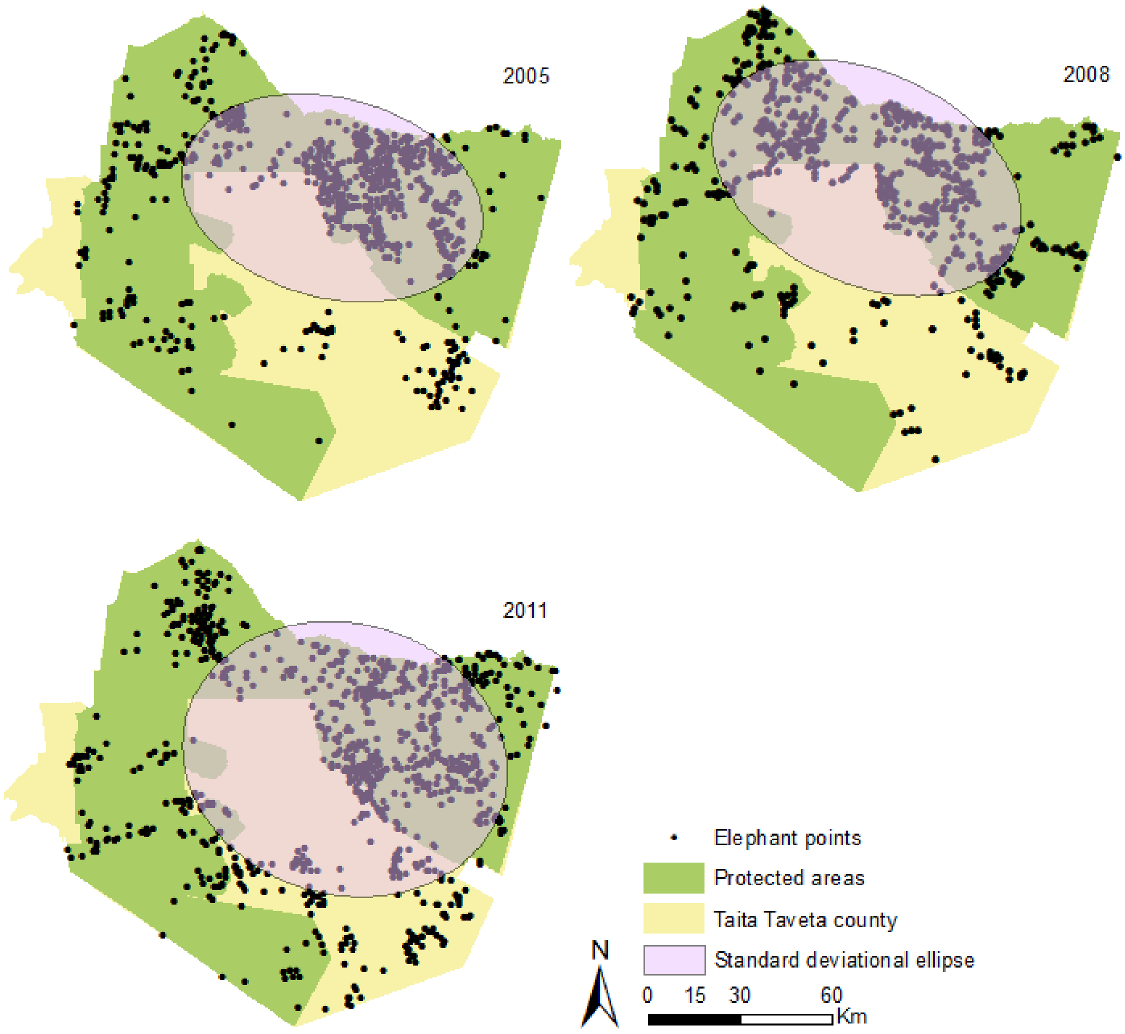

Figure 13 Standard deviational ellipses of Elephants weighted with herd sizes for 2005, 2008 and 2011.

The largest herds for each year was located in different areas for each year. In 2011 the largest herd included 120 elephants and was located in the southernmost point of the county. In 2008 the same number was 114 elephants and the herd were located outside of the protected areas, near the eastern border of the county. Lastly for the year 2005 the largest herd consisted of 163 elephants and was located inside the Tsavo West National Park in the southern areas of the county. In the year 2005 there was also few other noticeably large herds (143 and 110 individuals), whereas for the other years there was only one much larger herd and the others were significantly smaller. From the two herds in the year 2005, the larger was located near the largest herd in the southern parts of the county, and the slightly smaller outside of the protected areas, in the eastern parts of the county. Locations for the large herds thus varied greatly for each year but they were never located in the main hotspot areas.

The herd sizes for each year stayed quite constant. The average herd size was around 10 for each year and the distribution of herd sizes didn't vary much. The number of elephants changed for each year (see page 15), but only few larger herds were present each year. For all of the years 90% or more of the elephants were either alone or part of a herd sized smaller than 25 individuals.

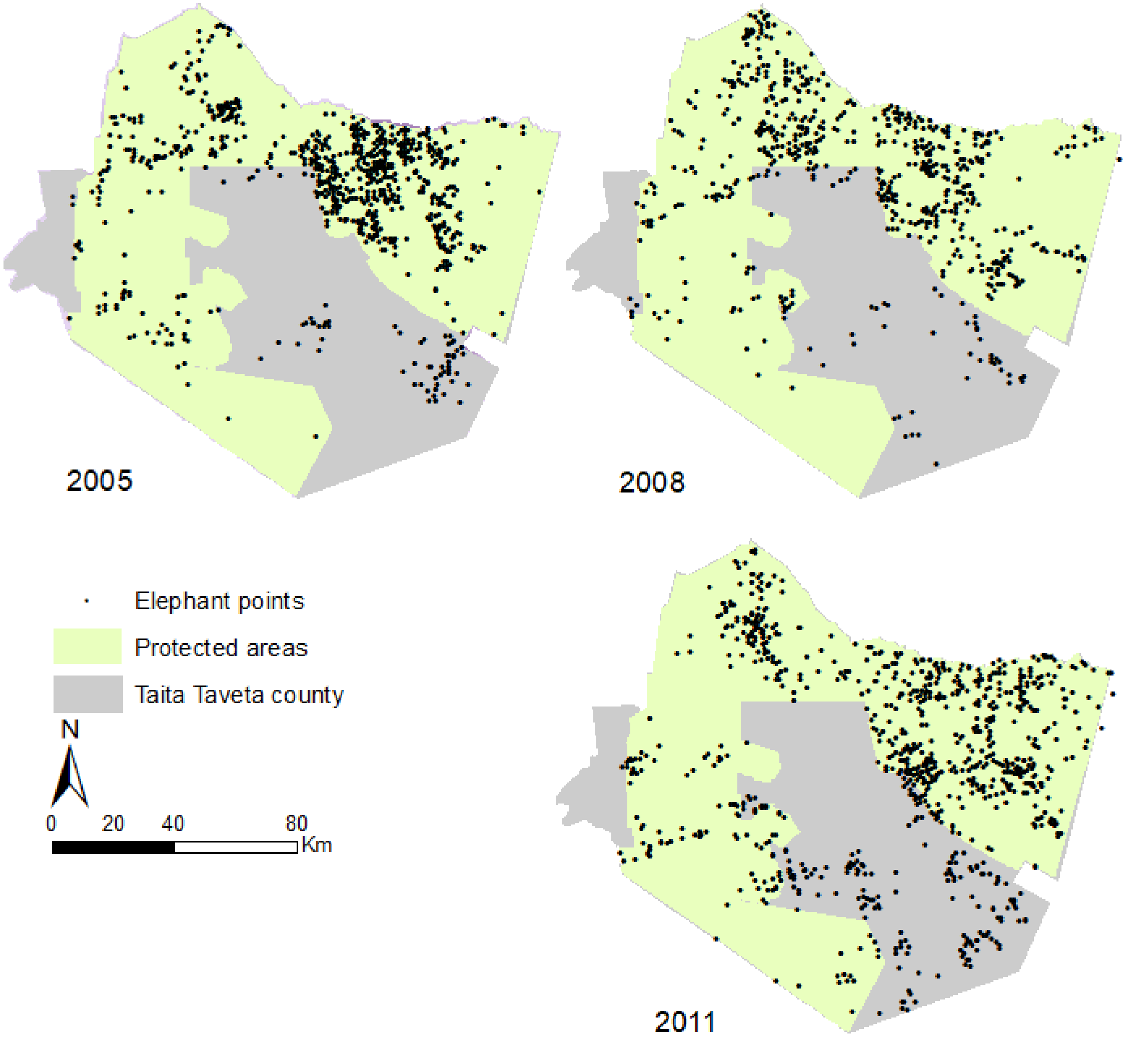

Figure 14 Elephant locations in Taita Taveta County. Each point represents either an individual elephant or a herd.

4.2. Correlation between environmental variables and elephant density in Taita Taveta County

The results of the correspondence testing are presented in tables 4, 6, and 8. The values indicate the strength of the correlation between each environmental variable and elephant density. Positive values indicate positive correlation whereas negative values indicate negative correlation. The closer to 1 or -1 the values are, the stronger are the correlation. Values close to zero indicate low correlation. Significance of the correlation are indicated with * if the correlation is significant in the level of 0.05 and with ** in the level of 0.01.

4.2.1. Correlation of environmental variables and elephant densities in the whole Taita Taveta County

For the whole area, correlations between each environmental variable and elephant density are all significant in 0.01 level. No individual variable has specifically strong correlation with elephant densities, but there are some variables that have really low values such as slope.

The strongest correlated variables change each year and there is a lot of variation between the years with many of the variables. For example, EVI and NDVI have positive correlation in year 2005 and 2008, but negative in 2011. So, in the first two years where the NDVI and EVI are higher there is also bigger density of elephants and in the last year when the NDVI and EVI grow, elephant density decreases. Also, House distance changes from positive correlation in 2005 and 2008 to negative in 2011 and at the same time its value indicates really low or no correlation.

Table 4. Correlations between elephant densities and environmental variables in Taita Taveta County.

	Elephant density 2005	Elephant density 2008	Elephant density 2011
Roads density	.145**	.334**	.230**
Roads distance	-.053**	-.169**	-.113**
River density	.299**	.371**	.159**
River distance	-.195**	-.278**	-.167**
Water hole distance	-.083**	-.107**	-.265**
Water hole density	.216**	.252**	.350**
House density	-.302**	-.269**	-.164**
House distance	.158**	.179**	-.011**
Protected areas distance	-.269**	-.344**	-.110**
NDVI	.161**	.099**	-.234**
EVI	.249**	.155**	-.152**
Slope	-.037**	-.016**	-.114**

Spearman rank correlations (n=79872) for elephant densities and environmental variables in Taita Taveta County. Significant correlations at the 0.05 level are indicated with * and the 0.01 level are indicated with **

Some patterns can nevertheless be found in the values between years. Many of the variables correlate strongest in the year 2008. These include variables consisting roads and rivers and the distance from protected areas. Some variables correlation's strength grows or lowers each year. House density and distance correlation become weaker each year and water hole density and distance become stronger.

Overall the results for correlation analysis for the whole area are quite mixed. In spite of the varying results some variables can be seen to have quite strong correlations in each year. These variables include roads density, river density and distance, water hole density, house density and distance from protected areas.

Table 5. Land cover types preferred by elephants in the whole county.

Land cover type	Elephants in year (%)		
	2005	2008	2011
Closed shrublands	7.18	3.92	12.37
Open shrubland	11.75	6.70	13.43
Woody savannas	11.62	4.58	6.95
Savannas	56.53	74.67	59.84
Grasslands	4.05	4.41	3.18
Permanent wetlands	2.74	1.63	0.71
Croplands	2.35	1.14	0.24
Urban and built-up	3.13	2.61	3.30

Percentages of elephants occurring in each land cover type of the area per year

Land cover analysis gives out clearer results. For all of the years over half of the elephants can be found in savannas. In the same manner, over half of the county area are covered with savannas (57% in 2005, 73% in 2008 and 67% in 2011). The rest of the elephants can be found more varying in the other Land cover types each year. Croplands, wetlands and urban areas have the least elephants each year.

4.2.2. Correlation of environmental variables and elephant densities in protected areas in Taita Taveta County

When inspecting only protected areas, all but one variable, are statistically significant in the 0.01 level. Wetness index which in the year 2008 fail to have statistical significance, is overall having poor correlation values each year. Otherwise many of the other variables have stronger correlations in protected areas than when studying the whole county at the same time. Only house density and slope have low correlations (in addition to the wetness index).

It needs to be mentioned that house density in the protected areas is almost non-existent and there are only few houses in the area. In the protected areas, house distance also acts differently than when inspecting the whole area or later the areas outside of protected areas. House distance and elephant density have negative correlation in the protected areas, meaning that when the distance to houses grows, the density of elephants decrease.

In the same way than in the whole county, NDVI and EVI have positive values in the first two year and negative value in 2011.

The same patterns between the years can also be found in the protected areas than in the whole county. Road and river variables have highest correlation in the year 2008, whereas water hole variables' strength grows each year.

Table 6. Correlations between elephant densities and environmental variables in protected areas in Taita Taveta County.

	Elephant density 2005	Elephant density 2008	Elephant density 2011
Roads density	,375**	.548**	.412**
Roads distance	-.152**	-.275**	-.184**
River density	.438**	.577**	.295**
River distance	-.359**	-.513**	-.336**
Water hole distance	-.175**	-.234**	-.386**
Water hole density	.286**	.353**	.495**
House density	-.026**	.020**	.115**
House distance	-.236**	-.190**	-.326**
NDVI	.286**	.324**	-.236**
EVI	.369**	.406**	-.135**
Slope	.103**	.082**	-.061**

Spearman rank correlations (n=51964) for elephant densities and environmental variables in protected areas in Taita Taveta County. Significant correlations at the 0.05 level are indicated with * and the 0.01 level are indicated with **

For the protected areas it is easier to notice the strongest correlated variables. These include river density and distance, roads density, water hole density and EVI.

Land cover behaves the same way than in the whole county area. The elephants inside protected areas are mostly located in the savannas. Again, over half of the protected areas are covered with savannas.

Table 7. Land cover types preferred by the elephants in protected areas in Taita Taveta County.

Land cover type	**Elephants in year (%)**		
	2005	**2008**	**2011**
Closed shrublands	7.91	4.37	15.21
Open shrubland	12.81	7.29	14.62
Woody savannas	12.37	4.74	7.24
Savannas	55.11	73.95	53.91
Grasslands	3.60	4.37	3.69
Permanent wetlands	3.02	1.46	0.89
Croplands	1.87	0.73	0.30
Urban and built-up	3.31	2.73	4.14

Percentages of elephants occurring in each land cover type of the area per year

4.2.3. Correlation of environmental variables and elephant densities in areas outside of the protected areas in Taita Taveta County

Outside the protected areas, more variables cease to have statistically significant correlations with elephant densities. Generally, the correlations are weaker in these areas as well.

The patterns noted in the two differently confined areas above, are not found in this area. EVI and NDVI act much the same than in the previous cases the exception being the year 2008 which fails to have statistical significance.

Since most of the variables have really low correlations or they are not statistically significant, the strongest correlated variables can be pointed out more easily. These include house density and distance, water hole density and slope.

Table 8. Correlation between elephant densities and environmental variables outside of protected areas in Taita Taveta County.

	Elephant density 2005	Elephant density 2008	Elephant density 2011
Roads density	-.233**	-.083**	-.086**
Roads distance	.137**	.073**	.025**
River density	.205**	.084**	-.017**
River distance	-.090**	0.007	.081**
Water hole distance	-.055**	-.083**	-.080**
Water hole density	.185**	.204**	.041**
House density	-.326**	-.216**	-.363**
House distance	.282**	.197**	.353**
Protected areas distance	.052**	-.184**	0.003
NDVI	.105**	-0.007	-.189**
EVI	.194**	0.002	-.126**
Slope	-.173**	.133**	-.173**

Spearman rank correlations (n=27908) for elephant densities and environmental variables outside of protected areas in Taita Taveta County. Significant correlations at the 0.05 level are indicated with * and the 0.01 level are indicated with **

The trend with the Land cover types is the same as with the other two areas. Most of the elephants are located in savannas. More elephants are located in the croplands than in the other two areas except in the year 2011 when the elephants are completely absent from the croplands and build-up areas.

Table 9. Land cover types preferred by elephants for areas outside of protected areas in Taita Taveta County.

Land cover type	Elephants in year (%)		
	2005	**2008**	**2011**
Closed shrublands	0.00	0.00	1.16
Open shrubland	1.45	1.59	8.72
Woody savannas	4.35	12.70	5.81
Savannas	72.46	80.95	83.14
Grasslands	8.70	4.76	1.16
Permanent wetlands	7.25	3.17	0.00
Croplands	7.25	4.76	0.00
Urban and built-up	1.45	1.59	0.00

Percentages of elephants occurring in each Land cover type of the area per year.

Table 10. Variables chosen to be used in MaxEnt modelling based on the correlation analyses. Variables include the best correlated variables from all areas and EVI.

Chosen variables		
Whole county	**Protected areas**	**Areas not protected**
Roads Density	Roads density	
River density	River density	
River Distance	River Distance	
Water hole density	Water hole density	Water hole density
House density		House density
		House distance
Distance from protected areas		
Land cover	Land cover	Land cover
EVI	EVI	EVI

EVI = Enhanced vegetation index

Overall, all the three different coverage areas resulted in differences in correlations between environmental variables and elephant densities. Most pronounced results are found in the protected areas where many of the variables had somewhat strong correlations and areas outside of the protected areas where only few variables had even some kind of correlation.

4.3. Modelling predictions of elephants' distribution in Taita Taveta County

For all of the areas, the environmental variables chosen in the previous step were tested in MaxEnt. Jackknife test was done for all of the variables and areas. All of the variables chosen based on the correlation, showed also the best response in the Jackknife test, so the modelling was further continued with the chosen variables.

Models were run for each year with all of the variables and with the chosen variables. NDVI was left out of the modelling, since it correlates a lot with EVI and EVI had slightly better response to the elephant densities in the correlation testing. EVI or NDVI weren't the strongest correlated variables available and direction of their correlation with elephant densities changed between the years. Nevertheless, vegetation index data was added to be used in modelling, since together with land cover, they are the only variables available that has variety between the years. If all the variables sued for each year are the same, then the models cannot be projected to other years.

Models for each year were trained with 70% of the data for said year and then tested with 30%. Models were also trained with each year and then projected to another year and tested with that new year's data.

4.3.1. Elephant distribution modelling in the whole Taita Taveta County area

As stated above, two models were run for each year. One with only the selected variables with the best correlation to elephant densities and another with all of the variables used in this study. The selected variables were house density, river density, roads density, water hole density, distance from protected areas and Land cover.

All of the years had moderate precision in both variable combinations and all years have quite similar performance.

Table 11. AUC values of models made for each year with two variable combinations.

	Variables used		
	AUC	**Chosen variables with LC**	**All of the variables**
Year	2005	0.772	0.804
	2008	0.756	0.771
	2011	0.728	0.709

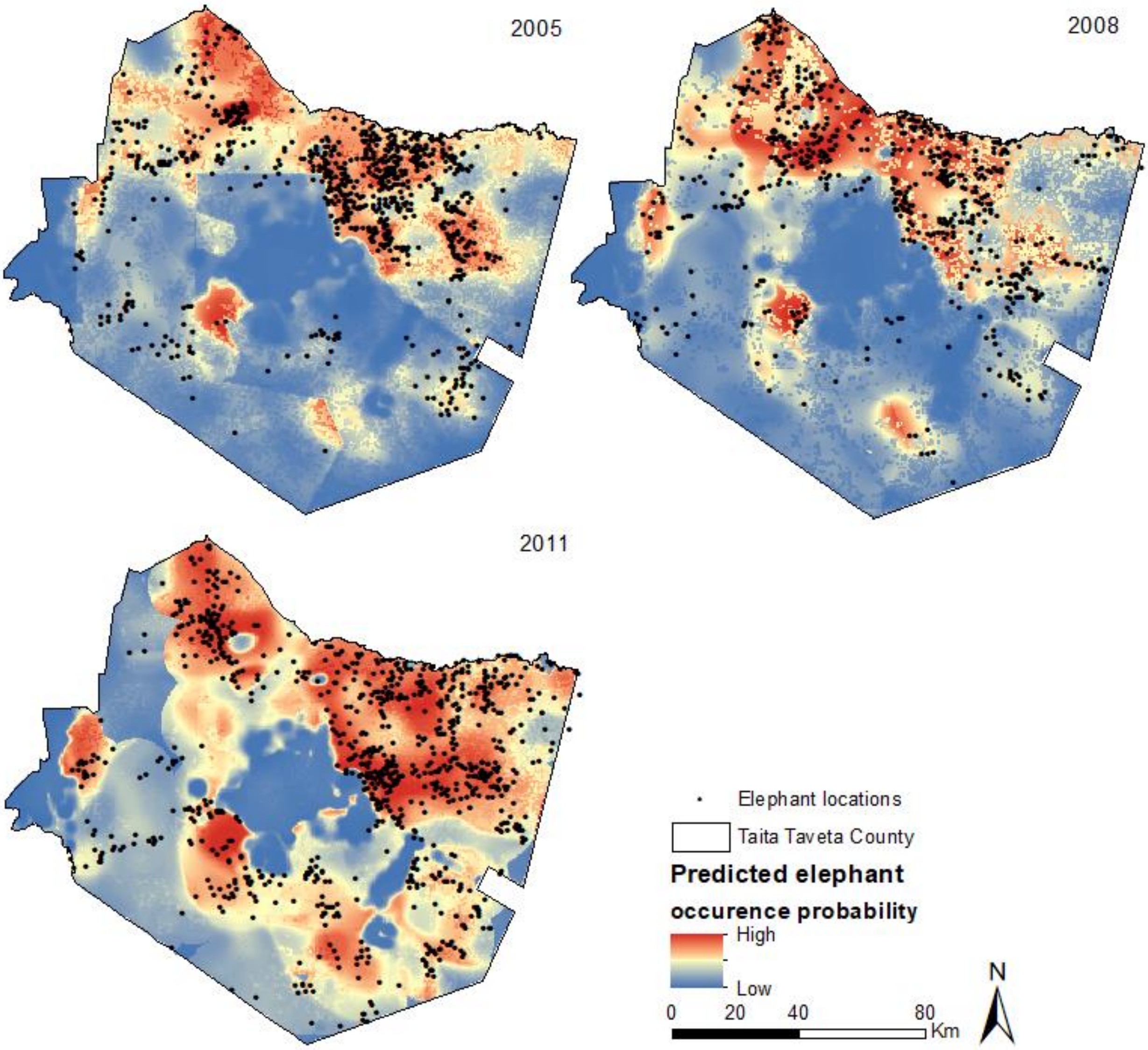

Figure 15. Predictions of elephants' occurrences for each year trained and tested with the same year's data using the chosen variables for the whole county.

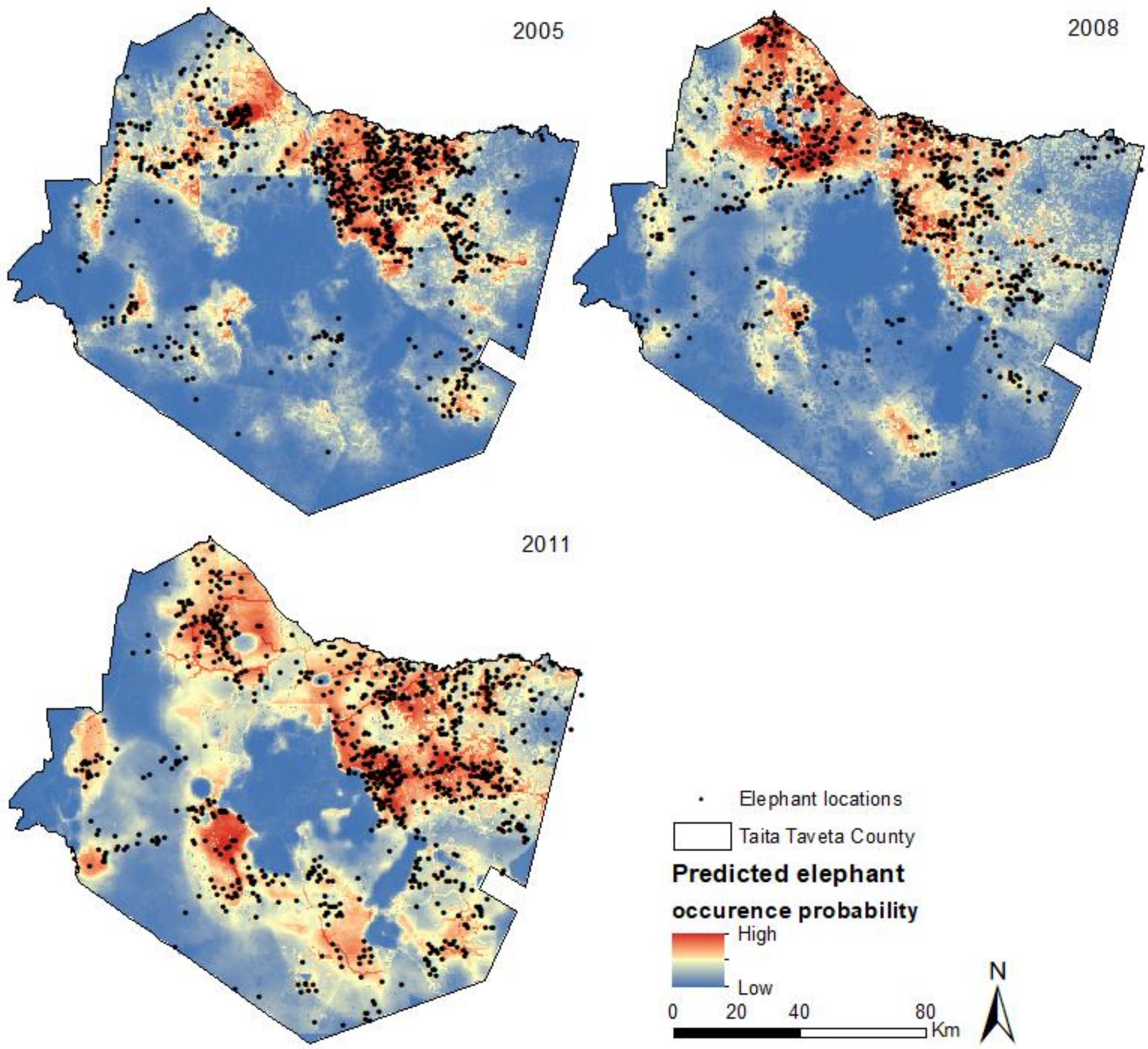

Figure 16. Predictions of elephants' occurrences for each year trained and tested with the same year's data using all variables for the whole county.

The predicted areas (figures 1 and 2) change when the data used for training changes. The most probable areas to have elephants grow each year but the maximum probability decreases. Each year the areas in the west get really low probability and thus would be thought to be unsuitable for elephants considering the variables used. The most western part of the county and the Taita Hills area in the middle have low probability and no elephants counted. When using all of the variables the probable areas are smaller than when using only the chosen variables, indicating that the variables left out are limiting the suitable areas for elephants.

The models were then tested with other years' data. First only the same chosen variables than above were used and then EVI was added to see how more of the yearly differences affect the results.

Table 12. AUC values of models using chosen variables and land cover for all years.

Data	AUC	Testing		
		2005	2008	2011
Training	2005	0. 772	0.735	0.668
	2008	0.746	0.756	0.670
	2011	0.713	0.724	0.728

Table 13. AUC values of models using chosen variables, land cover and enhanced vegetation cover (EVI) for all years.

Data	AUC	Testing		
		2005	2008	2011
Training	2005	0. 791	0.747	0.654
	2008	0.738	0.772	0.656
	2011	0.712	0.727	0.704

The performance of the predictions (Table 9 and 10) was moderate and quite similar than when the prediction was made for the same year and when made for other years. The year 2011 has the lowest performance when trying to be predicted with data from the other two years.

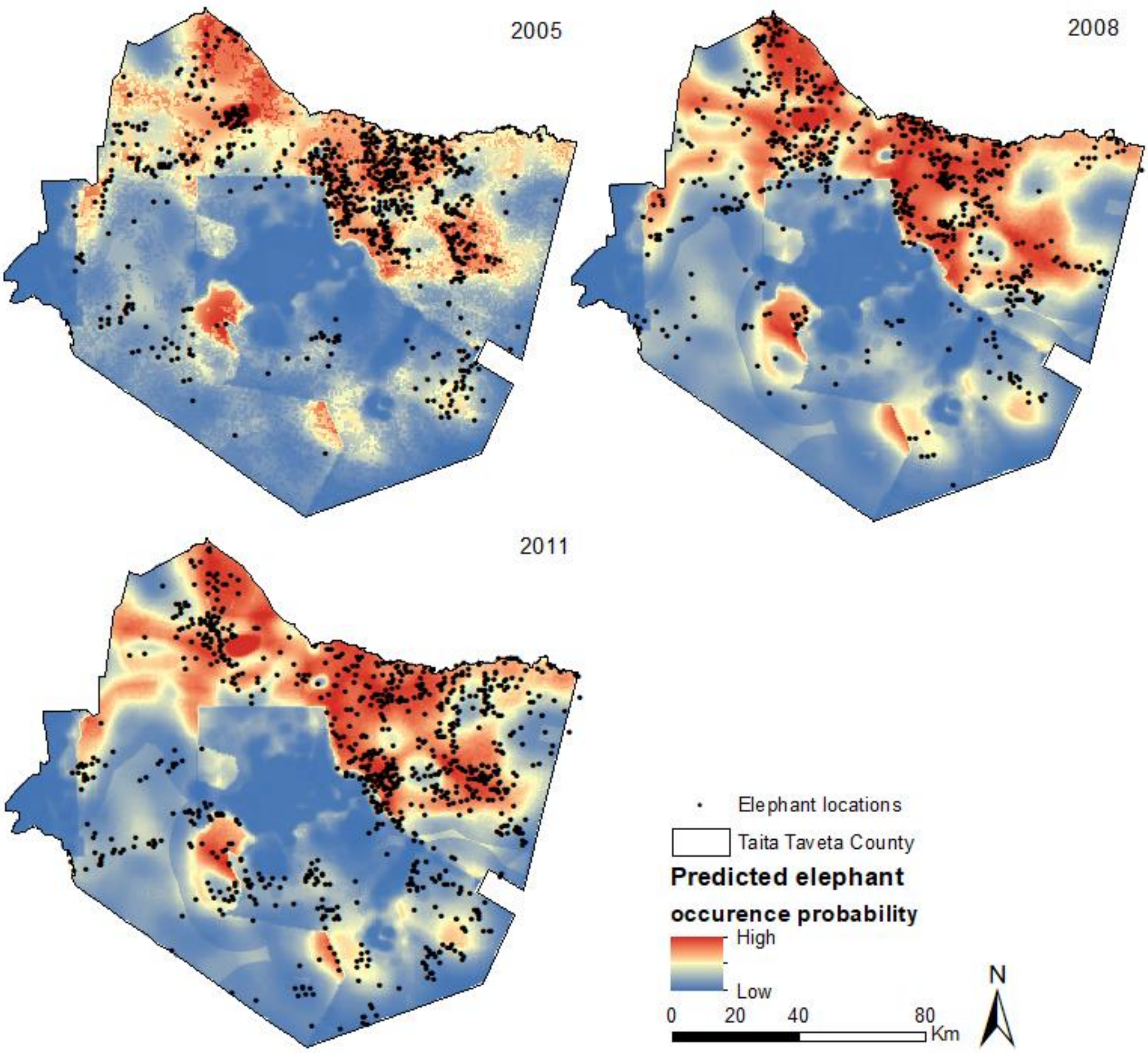

Figure 17. Predicted elephant occurrences for each year using a model trained with 2005 data and chosen variables.

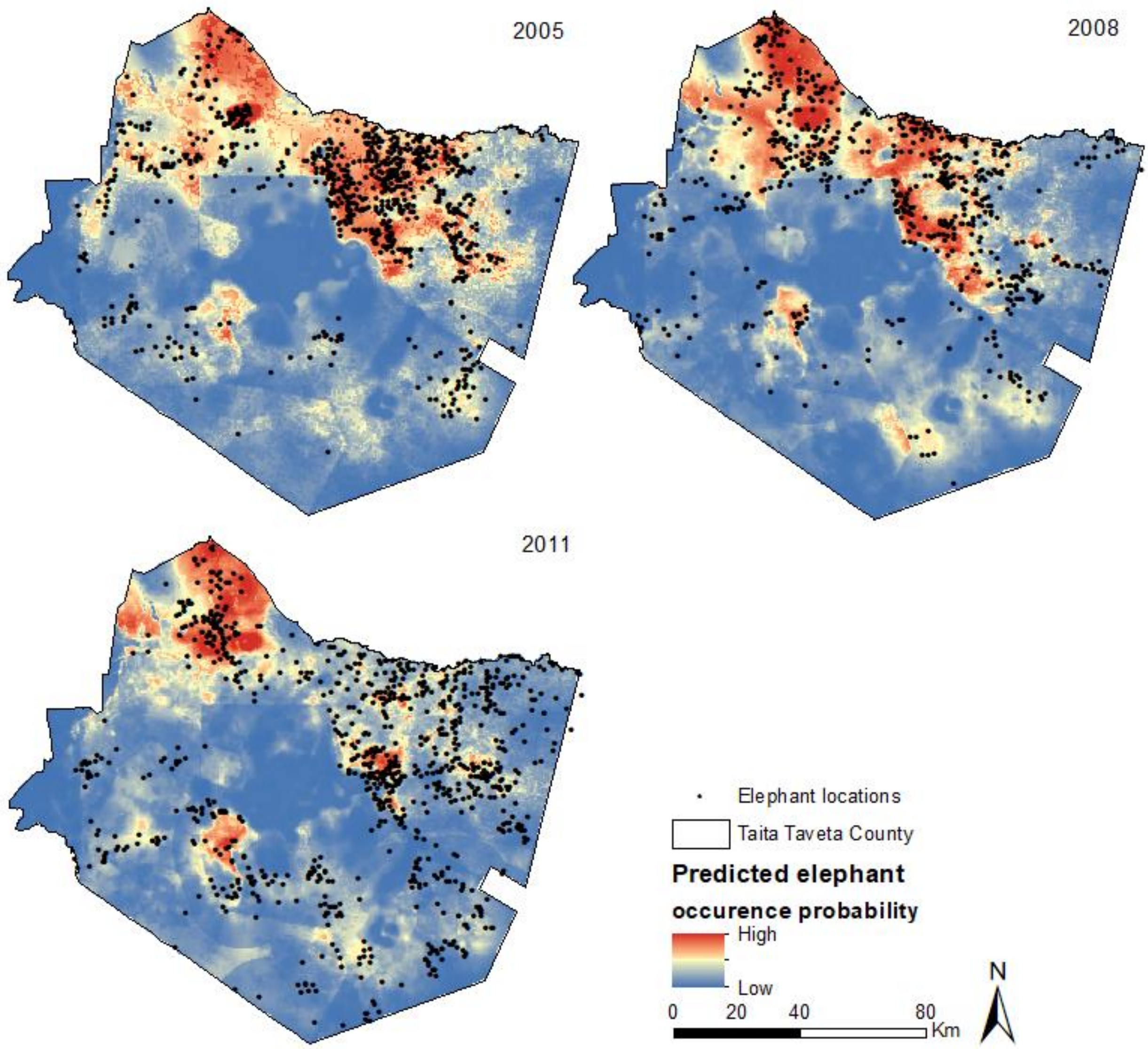

Figure 18. Predicted elephant occurrences for each year using a model trained with 2005 data and chosen variables with EVI.

Rest of the prediction maps from all years are listed in the appendices.

When looking at the predicted occurrence areas for all years with training data from 2005 (fig 17) the areas predicted with Land cover data stay similar each year even though they are projected to other years data. The same areas remain recognized and they mostly only change in size between the three years. The AUC scores don't have that much differences in them. Using also EVI with the chosen variables (Figure 18), the predicted occurrence areas have slightly more differences.

4.3.2. Elephant distribution modelling in the protected areas of Taita Taveta County

Since the protected areas had different correlations in the correlation testing, it was also modelled separately. Variables chosen based on the correlation were river density, roads density, river distance, LC, EVI and water hole density. Models were tested with the data from all the years. When using the same year's data 70/30 method was used (70 % of the data was used for training and randomized 30% for the testing). For the other years the model was first projected to the new years' variables and then tested with that year's data.

Table 14. AUC values of models using chosen variables for protected areas and for all years.

Data	**AUC**	**Testing**		
		2005	**2008**	**2011**
Training	**2005**	0. 742	0.700	0.631
	2008	0.682	0.720	0.626
	2011	0.650	0.690	0.708

The AUC scores have again moderate values and are quite similar to each other, the year 2011 having the poorest performance when being predicted. There are some areas predicted to be suitable for elephants that don't have any and also many areas that seem to be unsuitable that have elephants. The predicted areas have some similarities though. The same suitable areas can be found in all the maps, but the size and intensity vary quite.

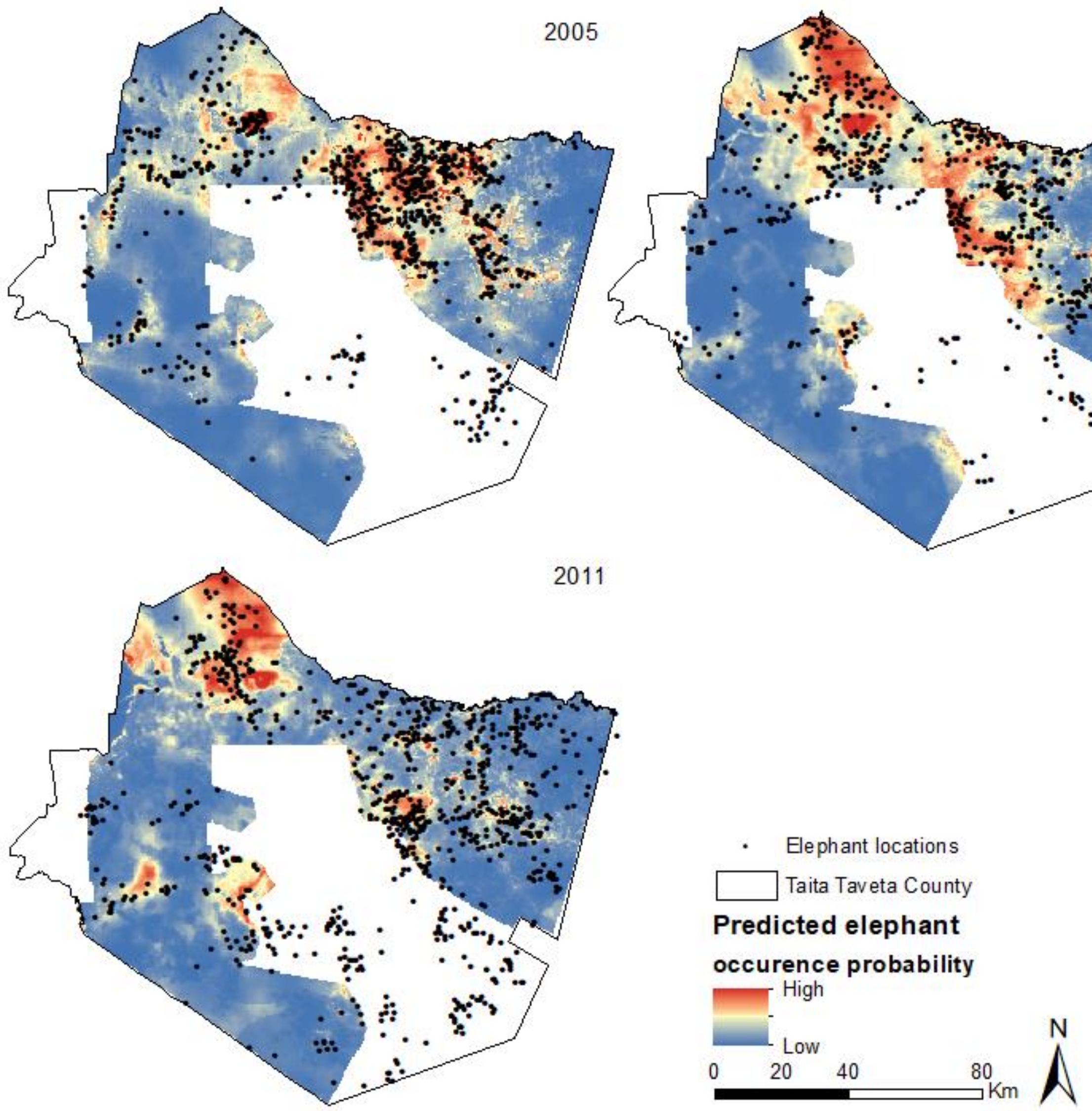

Figure 19. Predicted elephant occurrences for each year and for the protected areas, using a model trained with 2005 data and chosen variables.

4.3.3. Elephant distribution modelling outside of the protected areas in Taita Taveta County

Same as with the protected areas, since the correlation results were very different for the areas outside of the protected areas, it was modelled separately. Variables house density, house distance, water hole density, slope, EVI and LC were chosen. Testing was done the same way than with protected areas; with the same years than the training and then with other years' data when the models were first projected to those year's variables.

Table 15. AUC values of models using chosen variables for areas that are not protected.

Data	AUC	Testing		
		2005	2008	2011
Training	2005	0. 783	0.687	0.683
	2008	0.774	0.561	0.674
	2011	0.658	0.672	0.689

Table 16. AUC values of models using chosen variables for areas that are not protected when LC is changed to enhanced vegetation index (EVI).

Data	AUC	Testing		
		2005	2008	2011
Training	2005	0. 879	0.714	0.668
	2008	0.695	0.711	0.629
	2011	0.690	0.649	0.720

The results for the areas outside of the protected areas are quite similar to the results of the protected areas. The predictions trained and tested with the same year's data can have even good results, but the predictions made for other years are close to being poor. The results have more variety to them in this area than in others. Also, when LC was changed to EVI, some results got better and some worse, adding to the variety.

Mostly the same areas are being recognized in all of the predictions, but the variety in the size and intensity is even more pronounced than in the protected areas. For example, the models trained with 2005 data (fig 20), predict very few suitable areas for the elephants whereas the predictions made with the other two year's data predict larger suitable areas. Especially the predictions made for year 2005 change a lot in size and intensity.

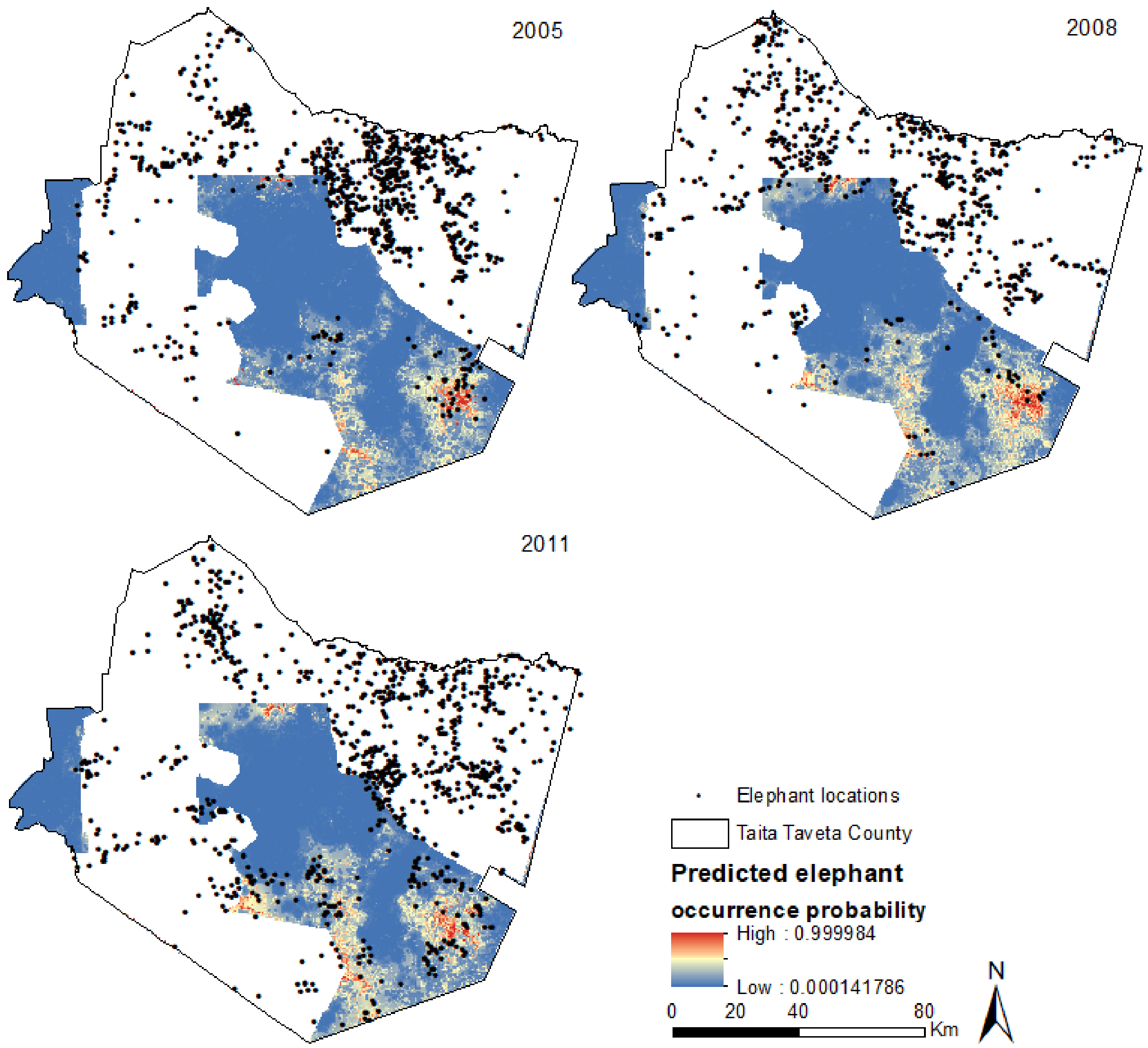

Figure 20. Predicted elephant occurrences for each year and for the areas outside of protected areas, using a model trained with 2005 data and chosen variables.

Overall the elephant models had moderate scores in testing. The areas predicted followed the patterns of the training data and even the models tested with same years data had only moderately scores.

5. Discussion

The results tell a lot about the elephants in the area and about the data used. The patterns, correlating environmental variables and predicted areas and the accuracy of the predictions change each year. Some similarities can be found in all the years and results though.

The elephant pattern analyses highlight the north-eastern area of the county as a hotspot for elephants. Elephants are more widely distributed around the area each year though and the total amount of elephants in the areas change.

Correlation with the environmental variables and elephant densities change between the areas and the years studied. Protected areas and the areas outside of the protected areas have different meaningful variables which emphasise the differences of the two areas and their environments. The meaning of the environmental variables changes from year to year, some similarities were however also found. In the two smaller areas, the meaning of the environmental variables were more similar each year and the most meaningful variables for all years were more apparent than in the whole county area.

Modelling gave out mixed results as well. The variables chosen were quite good at predicting the areas preferred by the elephants each year, but the predictions made for other years did not perform that well. Reasons for this could be many, but it seems that predicting elephant occurrences or densities for future could be hard. Although it needs to be remembered that elephants move around a lot and thus makes use of single occurrence points and prediction maps more challenging.

There is a lot of challenges in trying to study a specie like elephant and this study too has many questions still linked with it. Problems with data, methods, scale, chance and the nature of elephant itself are all affecting the study questions presented.

5.1. The number of elephants each year

The elephants are distributed differently each year in the county. Some similarities are found, like the focus of the animals being in the northeast parts of the county and the high-density areas are located also there. Differences include the overall distribution of the individuals around the county, in 2005 the herds seem to be located much closer to each other and in smaller areas, but in 2011 the elephants seem to be dispersed. What also changes each year, is the number of elephants. In 2005, there was7 744 elephants, in 2008 there was 6 961 elephants and in 2011 there was 8 544 elephants. Even though the total number of elephants vary, the composition of differently sized herds and numbers in the population stay quite un-changed. Since the available space and resources in each area are constricted, the changing number of elephants could very well affect the distribution of the animals.

The year 2011 has the most elephants from the three study years and it also seems to have the most widely dispersed herds and individuals. The number of elephants outside the protected areas is also the largest from all of the years in 2011, being 25% of the total population in the county whereas in other years it was around 15%. More elephants would need more space and thus it could be thought that there is connection with the population size and distribution, among other possible correlations.

But even though the year 2011 has the largest number of elephants and seems to have the most dispersed population, the number of elephants from the other two years offer some thought.

Though 2005 seems to be the least dispersed, it has more elephants than the year 2008 which seems to have the elephants dispersed more around the county than the year 2005 but less than 2011. So, the distribution of the elephants wouldn't thus be totally determined by the population size alone. The highest densities of the hotspots vary also, but not in accordance to the total population size. The year 2005 has the densest concentrations whereas the year 2008 has the loosest and 2011 is set in the middle thus meaning that there isn't a connection between the population size and the densities of animal concentrations.

The years 2005 and 2008 acted much more similarly to each other in the analyses than the year 2011 and so there is probably something else too that have affected the patterns we see now separating the newest year from the two others. For example, some kind of threshold could have been passed in the 2011 population size that forces the elephants to disperse more; the evidently rapid growth from 2008 to 2011 numbers might have an effect; there could have been some notable changes in the environment when coming to the year 2011; or the distributions could be the results of chance.

Even though the distribution patterns don't wholly seem to be following the population numbers, some of the environmental variables and their correlation with the elephant densities seem to follow the trend of the total number of elephants or the highest densities. Road distance and density have the strongest correlation with 2008 elephant data, whereas it is weaker in 2011 and the weakest in 2005. Thus, it would seem that there could be connection with the clustering patterns of the elephants and roads; when elephants cluster more the meaning of roads decrease. River density and distance also has the strongest correlation with 2008 data, a weaker correlation in 2005 and the weakest in 2011, indicating that there could be a connection with the total number of elephants and the meaning of rivers; the less elephants there being, the more they located near rivers.

Based on this it could be though that to some extent the number of elephants have an effect on the studied questions. More elephants in total would mean that the animals need to utilize also other areas than just the most suitable or preferable, for example disperse from the rivers to the water holes. More elephants would thus mean more mixed results in the correlation analysis and the modelling, since many more environments are used than when only fewer elephants are living in the area. Many other factors could have an effect on this though and so based on these results, nothing can be though sure, but it is a possibility that offers some interesting thoughts.

5.2. Vegetation indexes' effect on elephant distribution

Food sources were in this study described with EVI and NDVI indexes. Both variables indicate the greenness of the environment and can be thus thought to tell about the amount of available food sources. Since elephants are generalists and they can eat all kind of vegetation, the amount vegetation was thought to be enough to portray food. Especially in the dry seasons the food sources are more limited, and elephants don't have as much choice in the type of vegetation as in the rain season.

Even though elephants have a great need for food each day, EVI and NDVI both have only moderate correlations in this study. Many studies such as the ones done in Kuku game reserve and Kimana sanctuary in South-Eastern Kenya (Kioko et al, 2006) and in the Tsavo ecosystem (Maingi 2012, McKnight 2015) among other studies have underlined the importance of food sources for elephants and especially their meaning to home range selection and successful modeling of the specie. Even though the importance of food resources is unquestionably great, the results from this study do not suggest it. There could be some reasons that affect the results in such a way that they don't seem to have a great significance. It is doubtful that the meaning of vegetation would be minor to elephants.

Scale could be the one of the reasons for these results. De Knegt et al. (2011) suggest that elephants first choose areas based on vegetation characteristics in larger scale. And in these selected areas the home ranges are chosen based on available water supplies. This would mean that the whole county, some parts of it or other larger area, has enough food supplies for elephants and no major differences in the food supplies are present in elephant occupied areas or even in the elephant free areas of the county. Nevertheless, there still could be greener areas that draw in elephants at some locations, but the food options would not be a limiting factor for the elephants at this scale, if in fact the scale is wrong. Scale could also have an impact to the other direction. The MODIS vegetation indexes of 500-meter resolution used in this this study could have been too broad to effectively describe the vegetation. There could be smaller patches of green vegetation that won't show up on a broad scale and these patched could be attracting elephant to them from the close by areas.

Season could also offer some explanation for the results of this study, since the data used are from dry season when the overall greenness is low. So, if there aren't much green areas to be favored or the green areas are located so that they can't be reached, the results would also indicate a low importance of the resource (Mukeka, 2010). In the case of the Taita Taveta County, the greenest areas are in the Taita Hills region which is unreachable for elephants. If the greenest areas are unreachable, but still included in the analyses, the results would be somewhat skewed. There are also few other areas that show to be much greener than the rest of the county, but majority of the area seem to have quite low indexes in EVI and NDVI.

Interesting also about the EVI and NDVI is the differences in results for the years. In 2005 and 2008 they both had positive correlation, meaning that elephants were more in the areas were the indexes are high and vegetation is greener. But in 2011 the correlation is negative, which would imply that elephants are mostly avoiding high vegetation areas. In this case the elephants are not most probably avoiding green areas, rather the green areas aren't available and reachable for the elephants like stated above. When comparing the distribution of the green areas between the years, the year 2011 has noticeably smaller high value areas for EVI and NDVI (figures 8 and 9) and the only intensive green areas are in the Taita hills region. This could be the reason why the year 2011 differs from the other two regarding the correlation of elephant densities and vegetation indexes.

Mukeka (2010) have also studied the correlation of the elephants and the environmental variables in Taita Taveta County and the results give out negative correlations for EVI and elephant densities in the dry season. This would support the argument that in the dry season the green areas are so little or unreachable that they don't have great meaning to elephant distributions. From the results it can be noted that the evaluation of the prediction models had similar results even when using EVI negative or positive years to predict the other. This would imply that the elephants in the year 2011 did not avoid the green areas, it was just mostly probably inaccessible for them. It is also observed by many (Chamaille-Jammes, Valeix, & Fritz, 2007; Danquah, 2016a; Leuthold & Sale, 1973; Sukumar, 2003) that in the dry season the water sources importance increases, and elephants gather around water holes and rivers and thus the meaning of vegetation can seemingly be lessened.

5.3. Water sources and rainfall's importance to elephants' distribution

Water sources is the other most often mentioned variable affecting elephant distribution and home range selection. Especially in the dry season it has been observed that the water sources' importance grows, and elephants gather around water holes, rivers and other sources of water (J. S. O. Ayeni, 1975; J. Ayeni, 1977; Chamaille-Jammes et al., 2007; Danquah, 2016b; Redfern et al., 2003; Mwambola et al., 2016, Wato et al., 2016). Water sources importance to other aspects of elephant and environmental conservation work has also been studied quite (J. Ayeni, 1977; Chamaille-Jammes et al., 2007), since the impact on elephants of available water sources is so obvious.

As the vegetation indexes didn't show to have a great meaning in the area, water sources' importance was noticeable in all study areas, which would support the results from other studies and areas. However, knowledge about which water sources actually had water in the time of the study would have been important to use. Empty water holes are unimportant for elephants and thus won't probably affect the distribution of the individuals. No data was available about the water sources status though and the importance of water sources could have been greater if the empty water sources would have been left out. Smit et al. (2007) remarked that even though water sources importance is great to elephants, all populations might not be limited by water sources for example, if the water sources are plenty in the area. In the case of the Taita Taveta County, the population seems to be affected by the available water sources and thus be limited by them.

Some sources claim that rainfall is the most important factor affecting elephants' location (Leuthold, 1977) and some have recognized its impact on elephant movements (Chamaille-Jammes et al., 2007). Rainfall is the source of water to many of the rivers and water holes that tend to be dry part of the year. Rainfall also enables the vegetation to grow greener and thus offers food sources for elephants (Leuthold, 1973). Fritz et al. (2002) has noted that even the larger scales elephant and other large herbivore number are correlated with annual rainfall, as they would indicate suitable vegetation. Water sources and vegetation has thus a close relationship.

Rainfall varies between the areas in Taita Taveta County (Leuthold, 1973) and could have given a lot new information about the differences between the preferred and avoided areas inside the county. Average rainfall data for the whole Kenya would have been available; however, it would have been too coarse to use in this study area. Nevertheless, the information about the differences between the years could still tell something also about the rainfall trends also in Taita Taveta County but for the use in the correlation analyses or in modelling a detailed dataset would have been needed.

The average rainfall in the whole country varied somewhat between the years. In 2005, the average rainfall in January was 28mm, in 2008 it was 33mm and in 2011 it was 26mm. The rainfall would so seem to have been more in 2008 and less in the two other years, 2011 having the least rain. Also, when inspecting the total amount of precipitation in the previous year of the counts, 2004 had an average of 666mm, 2007 had 711mm and 2011 had 646mm of rainfall. In this too the conditions concerning rainfall seems to have been better when reaching the times of the counts in 2008 than in the other two years. Nevertheless, it is hard to say if there actually was this kind of trends also in the Taita Taveta County, since the differences are quite small, and the estimates are based on the whole country. Wato et al. (2016) have also suggested that it is not the annual precipitation that affects the elephants the most, but the length of the rains. No knowledge about the length of the rains in the county are available either.

5.4. Factors affecting predictive models' performance

The models' predictions of elephant occurrences performed moderately at the best. Generally, the results for same year predictions were better than when trying to predict other years and working on the whole county gave out better average results than the smaller areas inside the county. Based on the results in table 10, the chosen variables are probably enough to use for modelling elephant occurrences in the area from this array of variables available though, because there isn't much different when using all of the available variables or only the selected.

There are few quite probable reasons for these only moderate results. Firstly, there is probably some invaluable information missing from the models. These could include for example rains, which were discussed above. Phillips et al. (2004) have stated that one of the most common reasons for modelling to not work is the missing variables. If the right variables are not used, then there is nothing to correctly predict the distribution on. There could also be factors that the models can't take into consideration, such as movement barriers that can also skew the results (Phillips et al., 2006; Kamino et al., 2012). Unimportant variables and wrong scale will also decrease the performance of the models (Pearson et al., 2006; Elith et al., 2009) and even though the environmental variables' meaning was tested and only the best correlated variables were used, it is still possible that for some variables their meaning isn't strong enough to be excluded from being irrelevant.

Generalist nature of specie can decrease the performance of SDMs. Elith et al. (2006) among others have noticed that predictions about generalist species tend to get lower AUC scores than predictions for specialist species. Since generalists, like the elephant, are suited to living in many habitats (European Environment Agency, 2018), distinguishing the best suited habitats can be hard. And with elephants, the preferences to these habitat choices could change seasonally, year to year, randomly, with the individual's age or by some other factor (Shannon et al., 2006; McKnight, 2015; Okello et al., 2015; Smit et al., 2007b). The preferences of individual elephants can be changing but the preferences could also be changed in such a large scale that the difference in distribution can be seen in the whole population as is can be noted from the elephant data used in this study.

There could be some factors that would explain these yearly changes in preferences and distribution. One such factor affecting the habitat choices in the whole population could be the number of elephants in the area. The elephant locations and numbers changed each year as did correlations between the environmental variables and elephant locations. Even though the focus of elephants was in the same area each year, the overall dispersion changed quite. Each year had different number of elephants roaming the area and the number of elephants could thus affect the distribution of elephants each year making the elephants more dispersed when there are more individuals in the area. If elephants are forced to use larger areas in some years, they might have to venture to less preferred or even unsuitable areas and thus it would also affect the results of this study. Also, for example, the yearly precipitation could be the cause behind elephants' dispersion around the area. In rainy years the elephants can be located more widely and not be limited to few water sources. It is though possible also that the elephants are selecting their preferred habitats and location based on no logical reason.

Regardless of the reason, elephants seemed to have somewhat different preferences towards areas and chosen variables each year in the county. Trying to predict a distribution based on a training data that behaves differently than the data in the year the predictions are made for, won't work reliably. The models can only consider the given training data's correlations with the environment and then project the assessed values to the new variables. One would have to know first how the elephant population being predicted behaves, or for example the number of elephants to know what kind of training data to use.

In addition to being a generalist specie, elephants also are widely distributed which often leads to reduced performance in models. Luoto et al. (2005) noticed that species that are widely spread have lower performance in predictive modelling and that this has also been noted by others as well (i.e. Segurado & Araújo, 2004; Elith et al., 2009). Although some have had no indication to the strong effect of distribution and model performance according to Luoto et al. (2005), contrary findings have neither been done. Uneven distribution leads also to the reduced performance of predictive models especially together with the wide distribution area. In wide and unevenly used distribution areas species are often not using all of the suitable habitats which would be thus affecting the model performance. And in the case of a generalist specie like the elephants, the suitable habitats are plenty.

The species distribution models tend to create predicted suitable areas that are larger than the species actual distribution but smaller than the potential distribution (Pearson et al., 2006). In the Taita Taveta County the predicted occurrence areas seem to larger than the actual areas in some locations but smaller or non-existent in others. The potential distribution areas of the elephant are probably large and the realized distribution areas are presumably changing a lot because of the specie's generalist nature and the moving habits. Thus, the predicted areas needed to be much larger to actually cover the areas the elephants are using and to cover also the habitat choices based on varying preferences of the specie.

Even though the models for the whole county performed better, the possible reasons behind elephant distribution and model performance can be understood more when inspecting protected areas and the areas that are not protected separately. These areas are addressed later in the text.

Based on these results, models could be made to predict the potential distribution areas for each year and to be used with incomplete specie's occurrence data. But to predict future or past distributions this way, more information and data would be needed concerning the environment.

5.5. Protected areas are favoured by elephants

The protected areas are made for animals to live in and so they should have sufficient water and food sources and suitable habitats. Because of that, it is expectable that majority of the animals would be living in these protected areas rather than in the surrounding lands with human influences. Continental wide survey of elephants (Chase et al., 2016) discovered that 80% of all elephants are living mostly inside protected areas. The same observation can be made in Taita Taveta County also, where large majority of elephants are living inside the parks and sanctuaries.

There are also fences in many places keeping the animals inside these protected areas, which is also the case in Taita Taveta County. Wandering animals are often driven back inside the parks especially in the case of elephants, to minimize the threat they possess to humans and their possessions. But too many animals or too little resources might drive individuals, herds or entire populations outside but also when circumstances are good elephants might still venture outside in search of nutritious crops for example (Røskaft, Larsen, & Mojaphoko, 2014).

Because the protected areas are lacking many of the factors that are harmful to elephants, other variables' importance grows. And since elephants don't have any natural competition or predators, they are fully driven by their own needs concerning the areas. And what elephants need are food and water, from which especially the water sources' importance is noticeable from the results of this study. These of course affect elephant distribution in other areas too, but there are more of the limiting factors to be considered too.

The modelling of the protected areas didn't give out any better results than when inspecting the whole county even though the correlations were stronger and the results clearer. What might be the reason is that because the areas are made for animals to live, the different parts of the parks are equally suitable or at least not unsuitable for elephants to live in. For example, the food and water supplies could be enough in the whole area. That is a possible problem with any variable though or in any area. Elephants also can live in many habitats and so don't seem to favour any specific types, which might make predictions inaccurate.

In the protected areas elephants seem to favour some areas more than others. Higher density areas can be found in the northern parts of the Tsavo West Park and near Voi town, inside Tsavo East park. These areas seem to have reasonably waterholes and a river close by, but so have other areas too. What we do not is if the other water sources were dry. The north parts of the Tsavo West park have much higher EVI values than in any other areas inside the parks. Tsavo East doesn't seem to have much difference regarding EVI values in comparison to the less densely inhabited areas. Leuthold (1973) has noted that there would be more rains in Tsavo West, which would add to the good features of the park. The models all make high probability prediction for these two densely inhabited areas. So even if it might not seem that the two areas have any significant differences to the other areas, it is probably the sum of small differences that make the areas so popular among elephants. There could also be other reasons that affect the distribution inside the parks, that cannot be taken into consideration in this study or missing variables.

Prediction of suitable areas for species is important part of conservational work. New protection areas for example are only useful if they are located in areas that are suitable for the protected species. It cannot be said from this study that if the environment is more suitable for the species in these protected areas or if they gather in there only because they are free from human influence and the environment isn't any worse than in the other areas. But if the areas protected would have unsuitable environment trough-out, the elephants won't and can't stay there. So, for conservational purposes to know what areas could support the elephants in this case, is vital. Humans and elephants use the same resources and so the protected areas are also formed to keep humans outside and give the species enough resources. Growing human population and changing environment is two of the largest risks for species worldwide, so more thought is needed to be put into conservation work and protecting areas.

5.6. Human impact on elephants

In the areas outside of the protected areas, elephants have to share their space with humans. Humans and human impact offer a lot of limiting factors for elephants' distribution and often are the reason for elephants limited living areas (Kioko, Okello, & Muruthi, 2006; Sukumar, 2003). It might be though that the areas where elephants have ventured to outside of the protected areas are well stocked in food and water since the elephants are willing to get closer to humans (Røskaft et al., 2014). Raiding fields is not an uncommon action regarding elephants near human settlements which is often thought to be the reason for elephants to get closer to humans (Danquah, 2016b; Røskaft et al., 2014). The results from the land cover analysis confirms that some of the elephants have been located in croplands, but that that number of elephants are only 7% at the best of the elephants outside of the protected areas. It is tough understandable that the elephants wouldn't linger in the fields because of risk of conflicts with human, but rather eat quickly and often in the night time and then move away (Røskaft et al., 2014).

Even though the food or water sources are attracting the elephants, they wouldn't probably be staying near them. Then the limiting factors, in this case humans, would be the force affecting the elephants' distribution in these areas. In the protected areas elephants don't have any predators or competition that would affect their distribution together with food and water source. But outside of the protected areas the risks are present. From the results of the correlation analysis this can also be seen, that the variables concerning humans have more meaning than in the protected areas.

Human-elephant conflicts happen when the two species collide, often in the build areas or near human settlements. Encounters between elephants and humans have risks for both species since they can cause harm to each other. For elephant's perspective, it is thus advisable to try to avoid humans to minimize the risks. Some risk is taken tough, as mentioned in the form of field raiding, but the elephants raiding the fields are probably only few in many (Røskaft et al., 2014). But other signs that imply human presence, such as houses or certain roads, might be driving the elephants away from those areas, or at least most of the individuals.

Houses seem to have a negative impact on elephant distribution as can also be seen from the results of this study. Population data could also have been used, but in this case, the houses are probably enough to indicate human presence for elephants and the population data wouldn't have added much more information. Densely habited areas like towns are more effective in keeping the elephants at bay than sparsely build villages, and in this study, this is addressed with the density layer of houses.

In the areas outside of the protected areas, also roads have a negative impact on the elephants which has also been noticed by Danquah (2016). In there the traffic and passing humans form a risk for close by elephants. But in the protected areas roads are favoured by elephants, since they form an easier passage across the lands (Maingi, Mukeka, Kyale, & Muasya, 2012; Mwambola et al., 2016). In the areas outside of the protected areas, some isolated roads might serve as a passageway for elephants, but mainly they are a limiting factor. Road surface material could also have an effect on whether elephants use them or not, but the data was not available for this study.

Cattle is a growing problem in the area (*Personal communication,* 2018a). The amount of cattle herded in the county is growing and more and more of those are also venturing in to the protected areas illegally. No actual numbers or other data is available about cattle in the county and it is making the cattle questions more complicated. Some estimates have been made as a part of species counts, and in 2005 it was estimated that the total number of cattle in the area was 130 000 and from which almost 40% were located inside the protected areas (Omondi & Bitok, 2005). The estimate includes a estimated 60% grow from the number of cattle in 2002 in the area.

Cattle affect the elephants and their distribution greatly, in the protected areas and also outside of them. Firstly, cattle is a sign of humans and elephants mostly try to avoid humans (Ngene et al., 2017). Only the smell of cattle might be enough to drive elephants away, since they do not want to venture too close to humans. Also, the herders are often actively driving the elephants farther away from their herds. This happens especially when the cattle herds are located close to a water source and elephants might possess a threat to the cattle or the herders want to keep the water source for them a while longer.

Secondly, cattle and elephants use the same sources of food. The problem with food sources comes from the fact that elephants are in many places having too large densities and are destroying their environments (Glover, 1963). Cattle too is herded in huge herds and they are often kept at a site as long as there is food to eat. When they move on, the surroundings are easy to notice from others, since the plants are almost wholly eaten or stomped down. Evidently, the environment is under a lot of pressure and the areas that are destroyed take a long time to recover if they recover at all. All the areas destroyed by any specie is away from them all and thus it's limiting the suitable living areas of elephants among other species.

The herders don't have any regards towards the environment since it's not theirs and there is always some other place close by to herd the cattle to. The cattle is herded each year further and further into the protected areas and there haven't been much to do to stop them yet (*Personal communication,* 2018b). The problem has been recognized and efforts have been made to develop solutions.

The cattle thus have a large effect on elephant distribution and densities. It could be said that cattle should be though as one environmental variable when modelling elephant distributions because of their limiting effects on elephants. But just like the elephants, cattle herds are always moving about and hard to track. There is no available data about them and the issue is often political and thus sensitive to be addressed in studies.

Poaching is the most harmful of human actions towards elephants and Lidsay (2017) among others has declared it as the severe threat to elephants. Poaching isn't something that located in certain areas every time and could thus be taken into consideration in studies like this. Nevertheless, elephants are known to avoid places were poaching has happened (McKnight, 2015) and also areas were elephants have been culled (Chamaille-Jammes et al., 2008). So popular poaching and culling areas might be avoided by elephants for long times. It has also been noticed that poaching often happens where elephant densities are high (Maingi et al., 2010). Other factors too add up to the potential risk areas for poaching, such as good road network or closeness to park boundaries. So even if some areas are otherwise suitable for elephants, if there have been elephant deaths, the areas might not have that many elephants living in them than could be thought.

Models for the areas outside of the protected areas performed the poorest from all of the models run and had the most variability in the predicted areas according to the training year. Possible reasons for the poor results are probably the same as in for the other areas: some important data is missing. Also, since these areas are highly affected by humans, the uncertainty of the safety of the areas for elephants could affect the elephants' distribution to be more be based on chance. This would somewhat explain the variety in the predicted areas. Also, in these areas the elephants could also be just passing by, traveling from one suitable area to another trough un-suitable areas. Nevertheless, the reasons behind elephant patterns in these areas, I would think about using these variables for predictions of elephants' distributions.

5.7. Elephant movements and home ranges

Elephants move around a lot and their home ranges are large. The counts made by KWS capture just a glimpse of the elephants' movements and might not even tell about the preferred areas of the specie if they happen to be crossing an unfavoured area at the moment of the counts. The locations of elephants could be different if the counts were made just a week after or even few days earlier and so the movements of elephants could cause some problems. Elephants also are capable of living in different habitats and could thus favour many different places in case of vegetation and land cover and could be continuously changing their habitats further increasing the difficulties of defining suitable living areas and conditions.

In this study the problem of moving elephants and large home range was tried to be avoided as much as possible by using elephant densities in the correlation analyses rather than single elephant locations. Also, the cell size used (500 × 500m) was considered being enough, since more detailed data probably wouldn't have much difference to the elephant for which 500 metres is really small distance. In spite the movement behaviour being considered in this study, the results still could be skewed. For the modelling, precise location points had to be used, so the correlation analyses made in part of MaxEnt modelling have the problem mentioned above.

Often elephants are studied using ground collected data (McKnight 2015) or by radio collaring few individuals to track their movements (de Knegt et al., 2011; Shannon et al., 2005). This way the actual total area of the individuals or herds can be studied, but it also creates other challenges for the study. Tracking of individuals is slow, hard and expensive and so the possibilities of this kind of aerial count data are compelling. Usually only few elephants are tracked and so only some individual's preferences and habits can be learned of. When you a have such a large data set, as the ones used in this study, the whole populations trends can be noted and even if the individual locations won't tell much and can be misleading, the number of elephants could cover for those errors and overall trends can be possibly found.

Although elephants move around much, Leuthold and Sale (1973) has observed in the Tsavo ecosystem that the elephants tend to return to the same areas in the dry season even if they venture to other areas for a short while. Elephants tend to move in relation to rains according to Leuthold and Sale's study but once they have utilised the benefits of the short rains elsewhere they re-turn to their original area. And although the home ranges of elephants are large, they tend to be smaller in the dry season (Leuthold, 1977; Shannon et al., 2005) and thus if the counts are made at the right time they could tell surprisingly much about the area actually preferred and often used by elephants. But even though the elephants' locations at the time of the counts might be more representative than thought, the specie's home range is still vast and the single location just a small part of the area used and so it cannot be forgotten.

5.8. Sources of error

There are some sources of error that might be affecting this study. Some possible sources of error where noted in the study itself but some could not be fixed. For example, the moving nature of elephants were noted and thus elephant densities were used mainly instead of the individual locations.

As noted, this study is missing some useful data that would have been probably important to include. These include rainfall, information about which water sources have water and cattle among some. Not mentioned before are fences and canopy cover, which could have also given important insight to the elephant distribution. Mostly in this case the data just wasn't available.

As many of the variables used were digitized from aerial photos, the errors involved in digitizing are also a concern. The aerial photos used for digitizing where not from the study years, which add on to the missing data problem since some years could have differences in for example houses. The aerial photos themselves could have clouds or other visual problems that decrease the number of observable targets. Some targets might be hard to point out even from a good photo and for example water holes are easily missed or confused with other objects. Generally, all carelessness during digitizing can alter the data. But, in this study since density and distance where used instead of single points, the errors in digitizing won't have probably affected the results much.

The cell size used was 500 × 500 metres for this study. It serves the purpose of the elephant data, since they move around a lot and even some greater distances are relatively short for elephants. But for the environmental variables such as land cover and especially EVI or NDVI, the scale might be too broad. Smaller patches are not noted in using cell size like this, which could lead to missing out some important locations and sources of food. But it is not sure if smaller scale would have resulted in better results but testing of it would probably provide important information.

With better and more precise environmental data and maybe a smaller scale, the results could have been different. Some data might not be available at all which would thus make modelling elephant distributions even harder.

5.9. Improvements and future study questions

The easiest way to improve the study made here would be to include some of the missing environmental variables. Variables like rainfall and cattle density are very probable to have a significant impact on elephant densities and distribution. Also, more precise datasets of the variable used would be beneficial. For example, only using water sources that are known to have water in the time of the study and to only use the buildings and roads that have been already build in each year instead of using the same buildings for all years.

There are many possibilities on continuing this study in the county. One possibility would be to repeat the study in wet season. Elephant patterns and environmental conditions change significantly with season. Also, elephants tend to have a larger home range in the wet season, since they don't have to rely on only permanent water sources (Leuthold, 1977; McKnight, 2015;

Sukumar, 2003). The densities of elephants reduce in the wet season and spatially individuals and herds are located further away from each other. Wet season increases the amount of usable water sources and food supplies in all areas.

Multiple years were already used for this study, but more could be also done with different years. Changes in areal trends, number of elephants in accordance to their distribution or distribution changes in accordance to environmental changes could be studied to mention few. Some of these could prove hard to study, since environmental data wasn't available for this study from before the year 2000. But the animal data that has been used in this study offers a lot of possibilities regarding year to year comparison.

Scale has been brought up in this study in discussing of the results. Different scales would so be also interesting to compare to see how the importance of variables change. Larger scale could increase the importance of vegetation for example, but also smaller scale could have the same effect, when the smallest patches of vegetation could also be considered in the analyses.

The two main parks in the county, Tsavo West national park and Tsavo East National Park are considerably different from each other. The vegetation and land cover differ in each park and the water and food sources are not equal. The parks are also separated from each other by a highway and a fenced railroad which make the movements between parks harder though not impossible. Each park could be studied separately to find out if different factors matter.

There might be even differentiation between the preferred areas in accordance to the sexes of elephants and the composition and size of the herd. With the elephant data that was used in this study, this could not be done with. But for example, McKnight (2015) have been studying questions about group composition and spatial distribution in Taita Taveta County by mostly using small elephant data observed in field and Smit et al. (2007) have studied mixed and bull groups' distribution differences in Kruger National Park, in South Africa.

All areas and all populations have their own distribution patterns and preferences and thus studies from different areas can't be used to make assumptions in other areas. So, one step further from this study would be to repeat the steps in other areas.

Many possibilities of studying elephant densities and patterns are available. Possibilities are focused mostly in small scale studies since they give out more coherent results and are easier to collect data for. Large studies are mostly focusing on more general aspect of elephants' lives for example food and water needs and physiology. Many of the questions have already been studied some but mostly broad comprehensive studies are still missing. Comparing and combining results from all scales of studies from different areas could be giving a lot information about the overall tendencies of elephants and their spatial distribution.

6. Conclusions

Some variables have clearly a greater correlation with elephant densities and the occurrence of elephants can be modelled moderately using these variables. Some important data is missing from this study that would further explain elephant distribution in the area. There are differences between the protected areas in the county and the areas that are not. Different variables are meaningful to elephants in these two areas mainly because of human impact.

Overall elephants are dependent on water and food sources from which the water sources are one of the most important driving variables for home range choosing. Outside of the protected areas the more limiting variables meaningfulness arise, and the most describing variables of elephant occurrences and densities are houses and roads.

Elephant densities and occurrences are hard to predict since so many variables have an effect on it and not all of the effects are known. Elephants also occupy large areas that are varying in size and habitats. Data is hard to gather and are missing for many of the environmental variables making this kind of broad study difficult.

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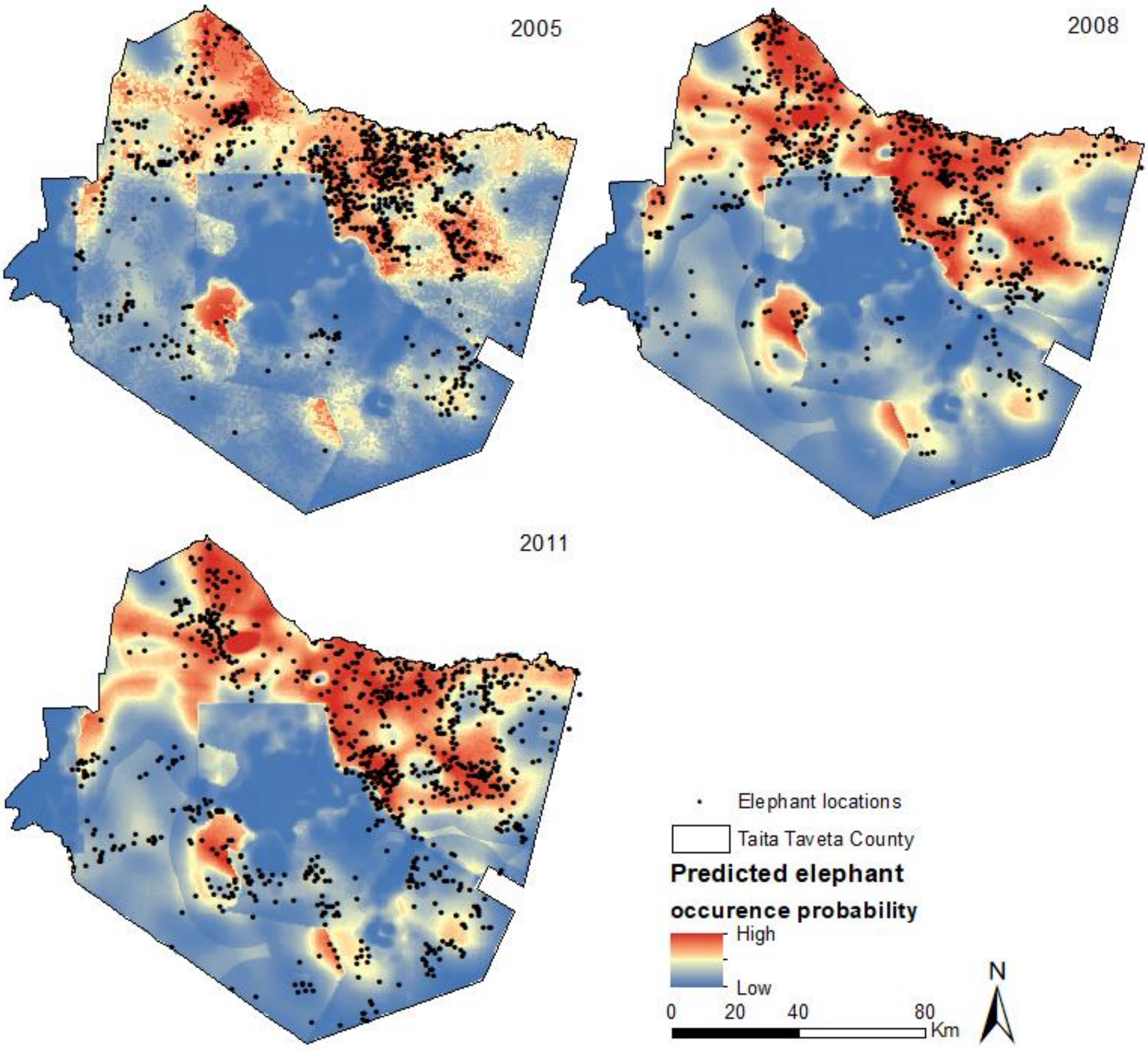
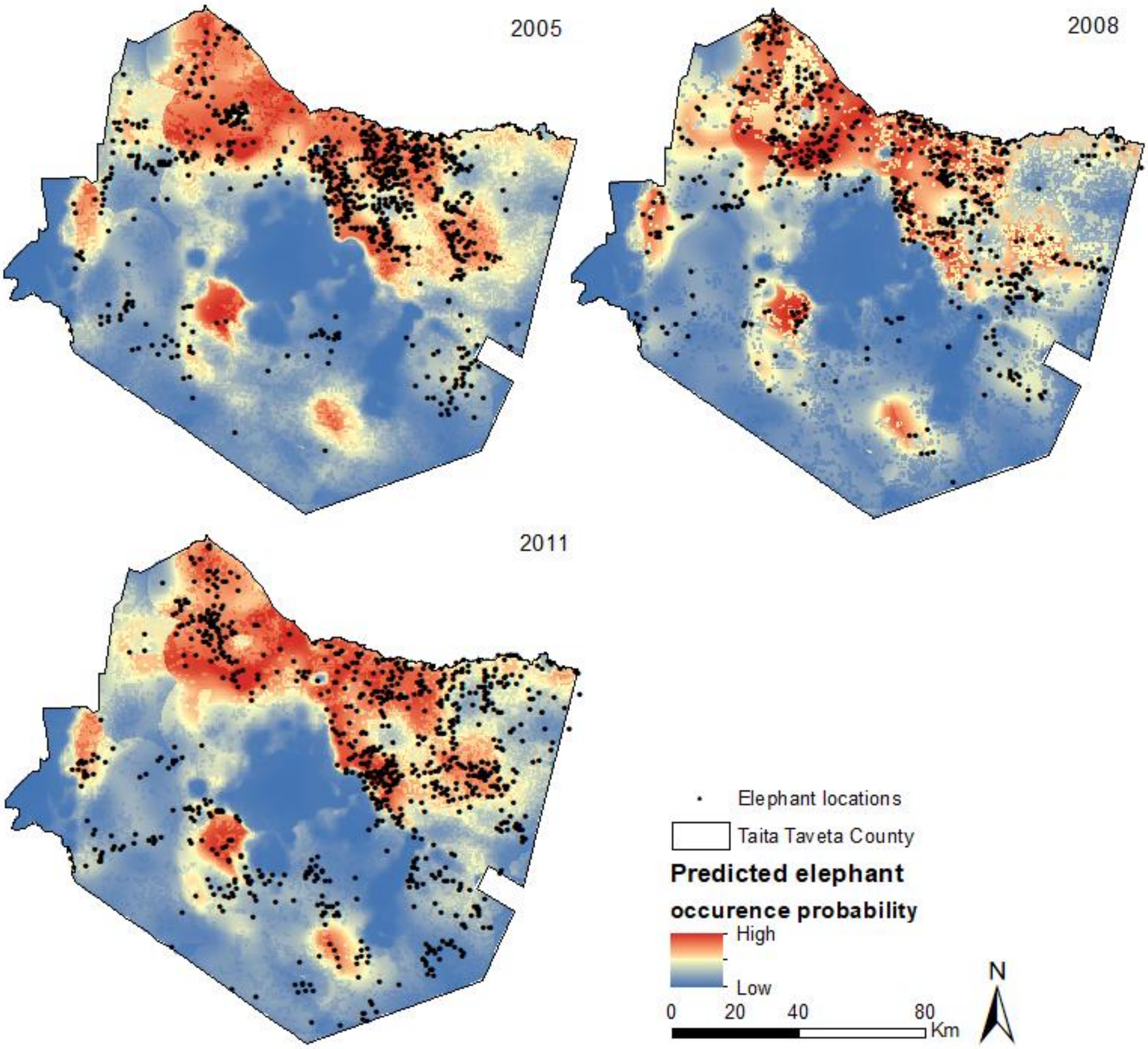
9. Appendix



Models trainer with 2005 data using the chosen variables for the whole county.



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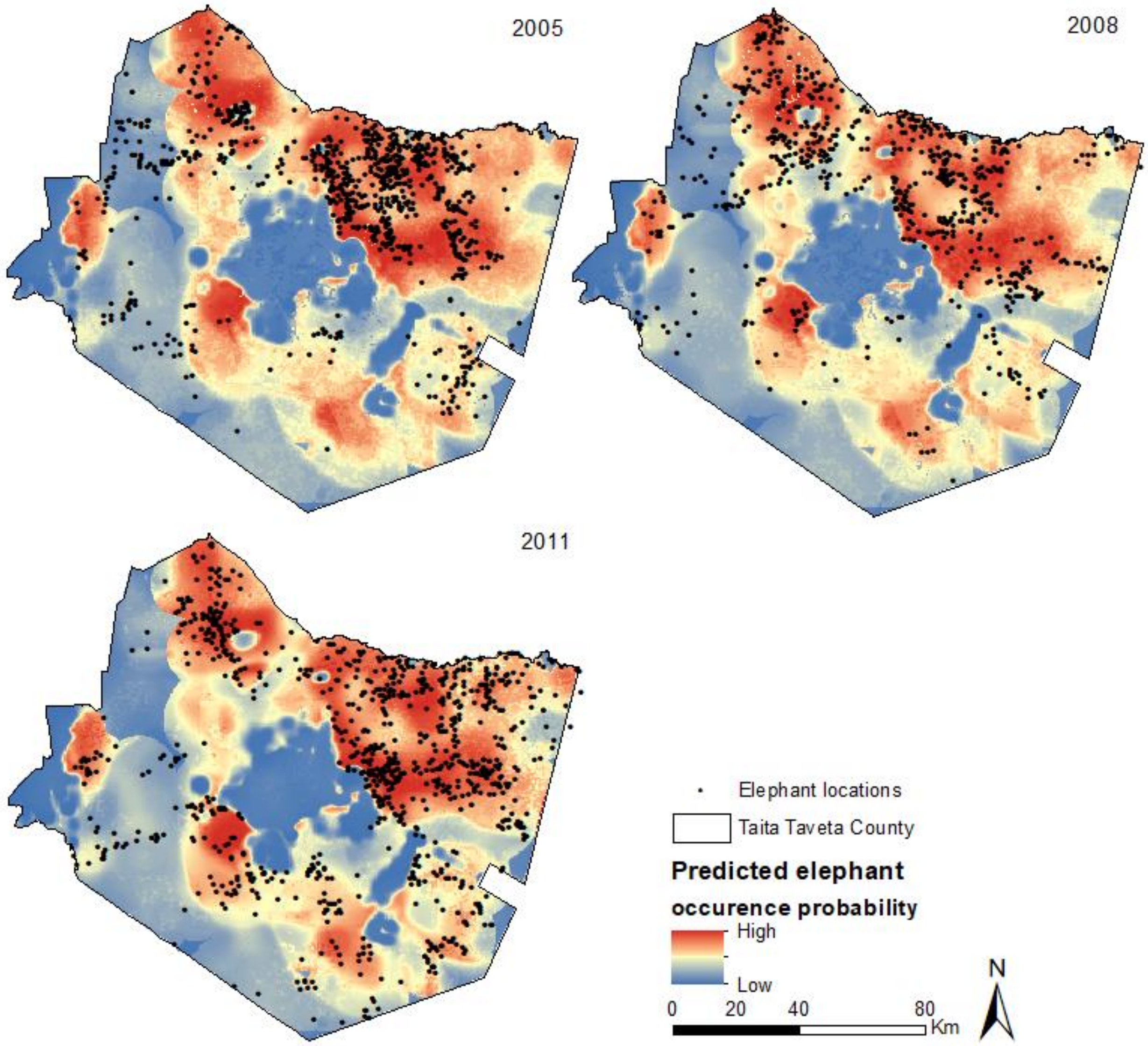
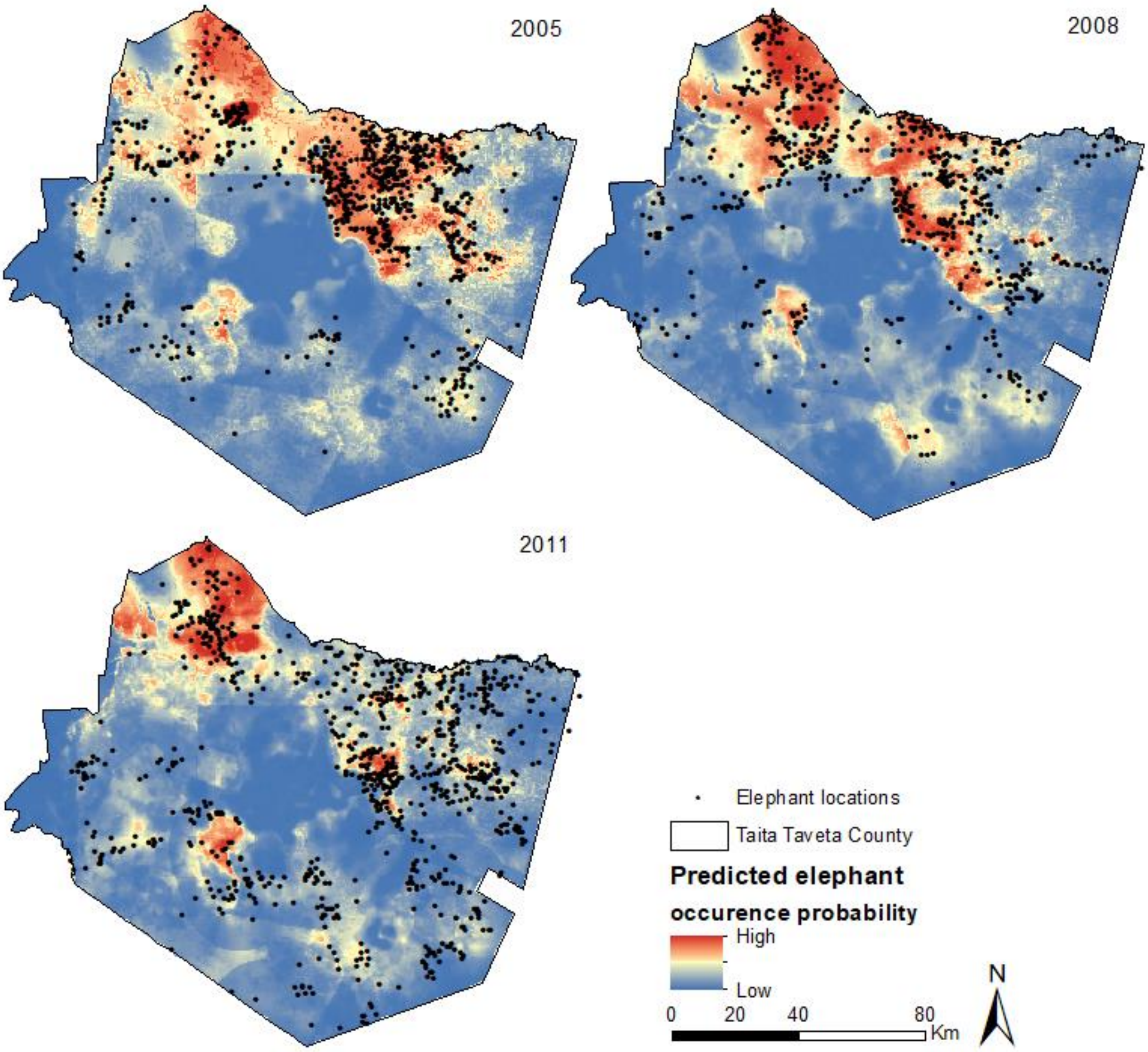
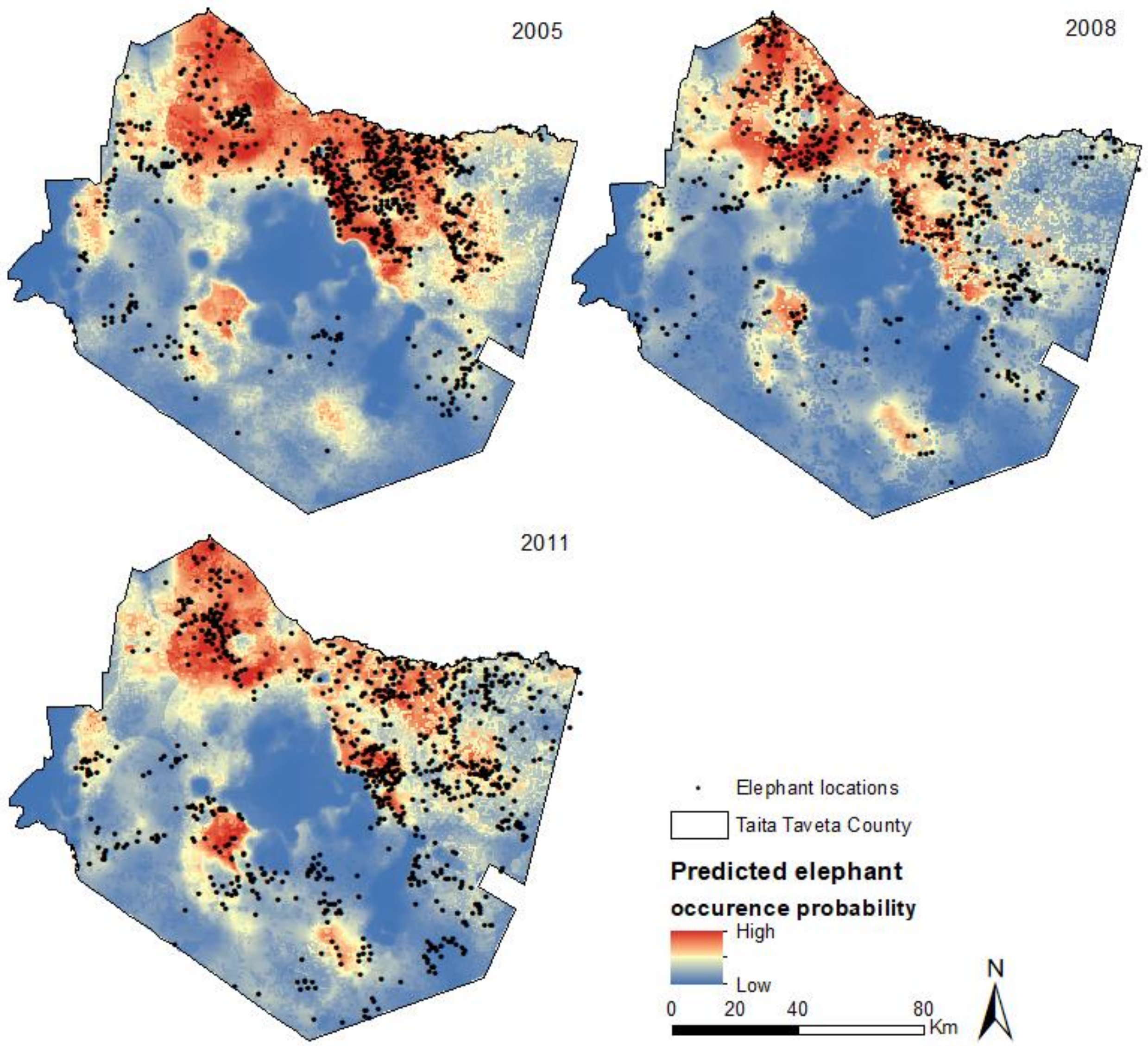


Models trainer with 2011 data using the chosen variables for the whole county.



Models trained with 2005 data using the chosen variables and enhanced vegetation index for the whole county.



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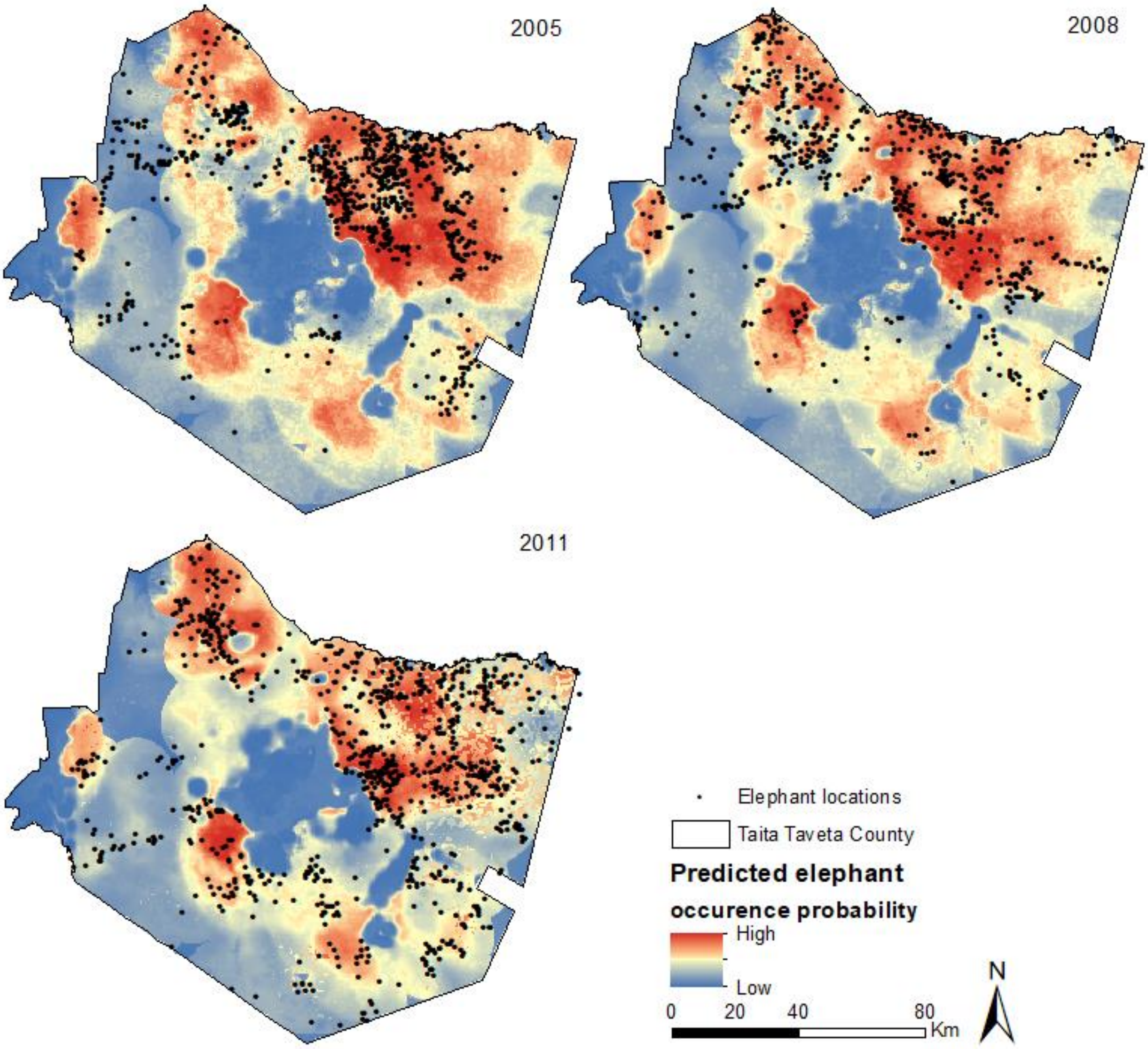

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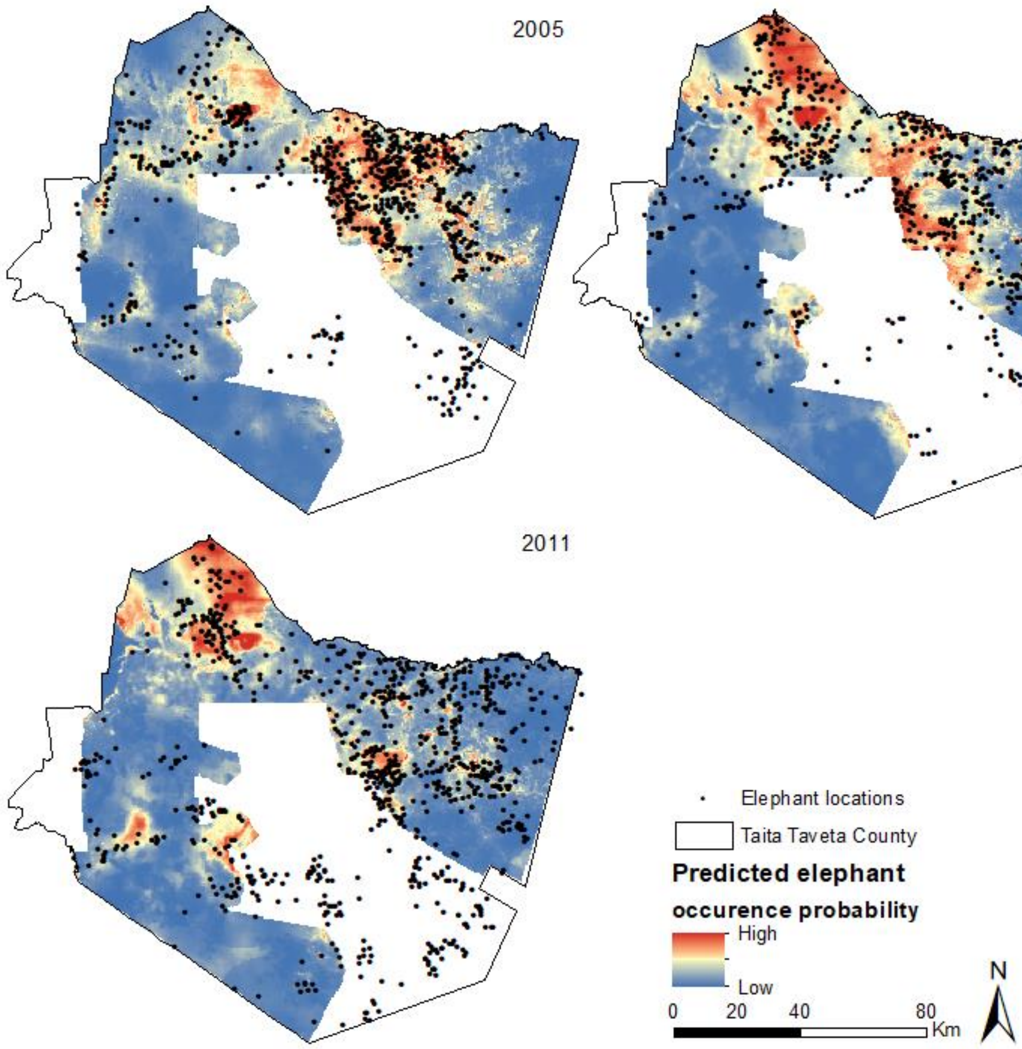
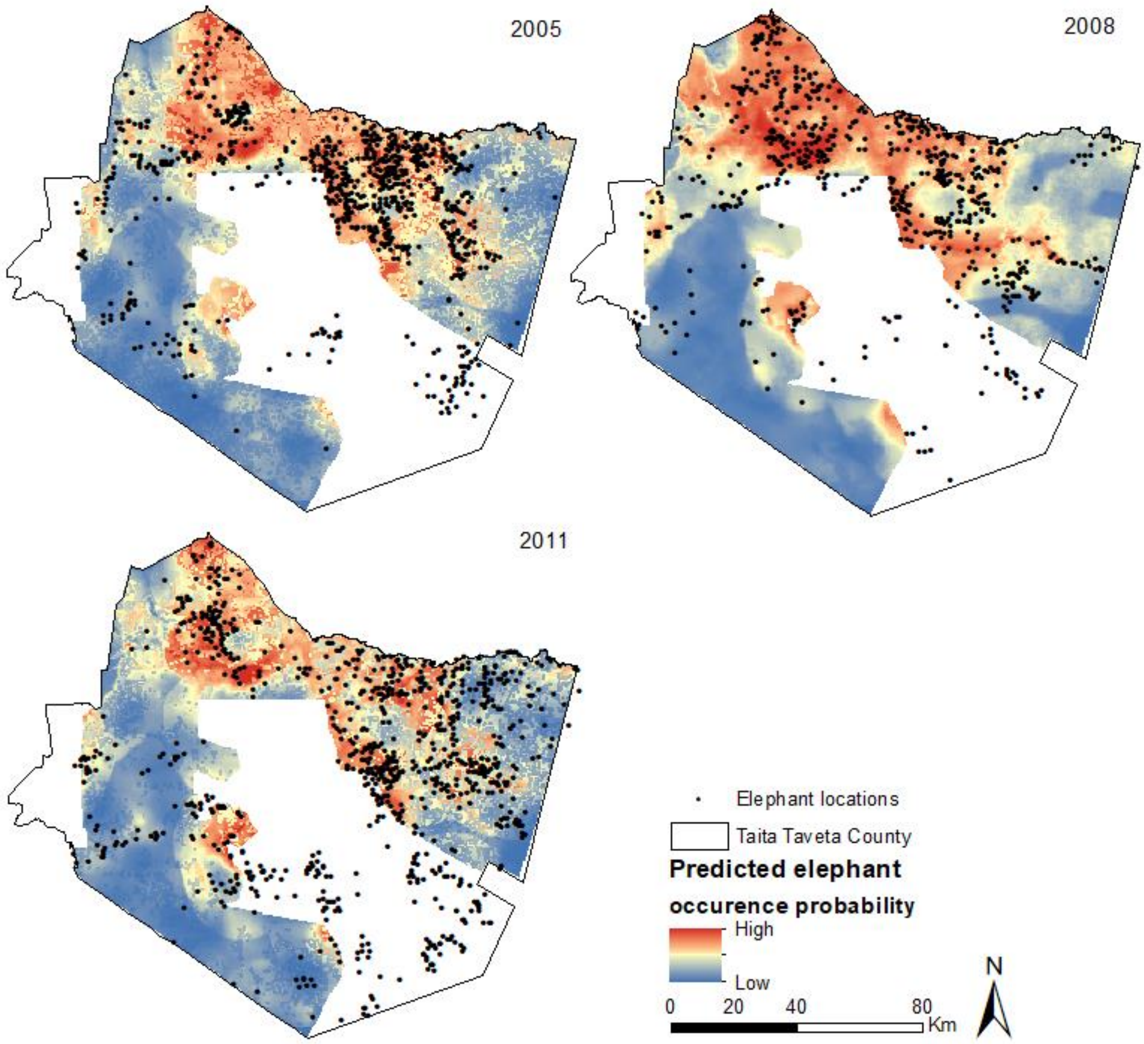


Models trained with 2005 data for the protected areas using chosen variables.



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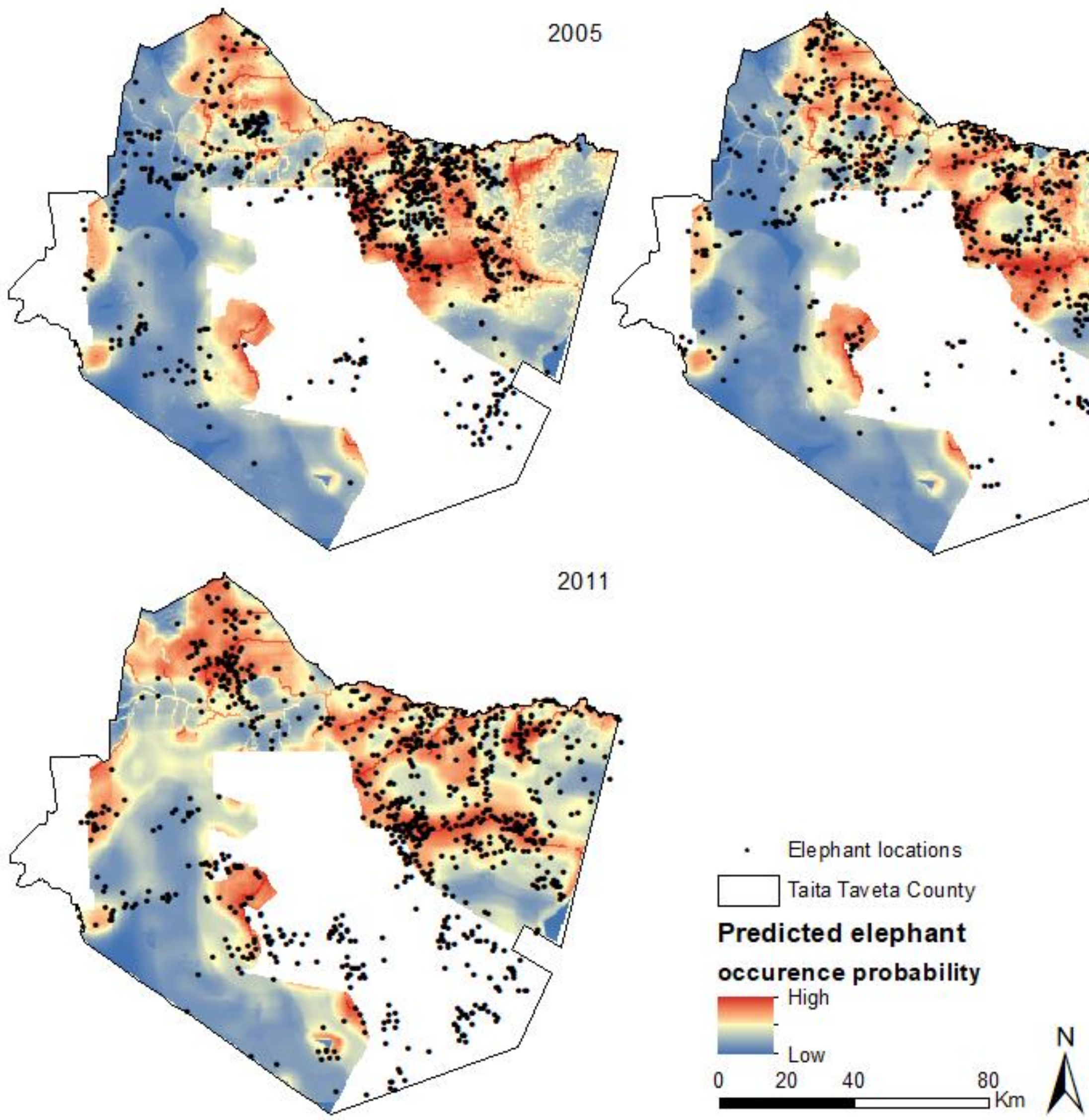

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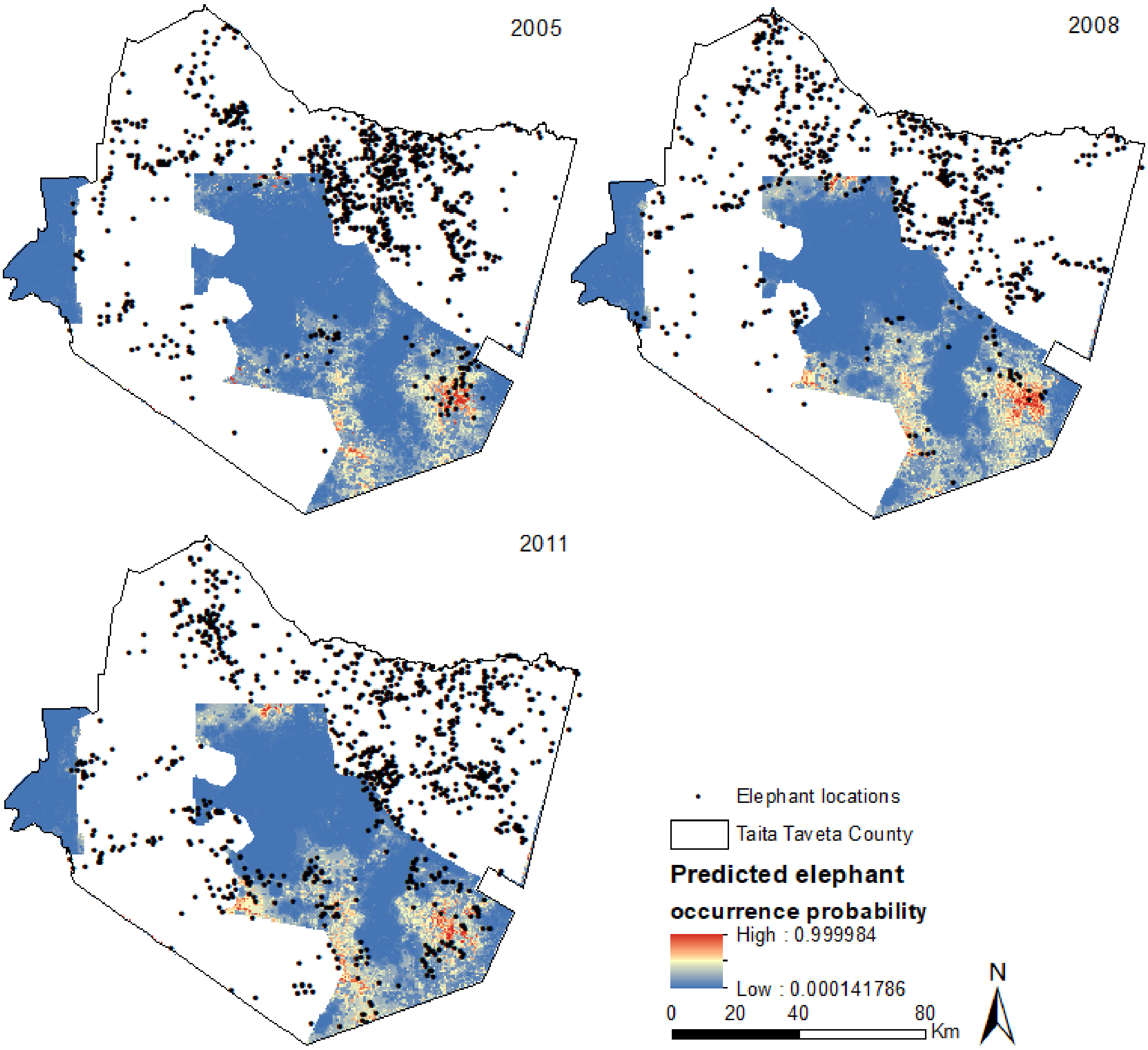
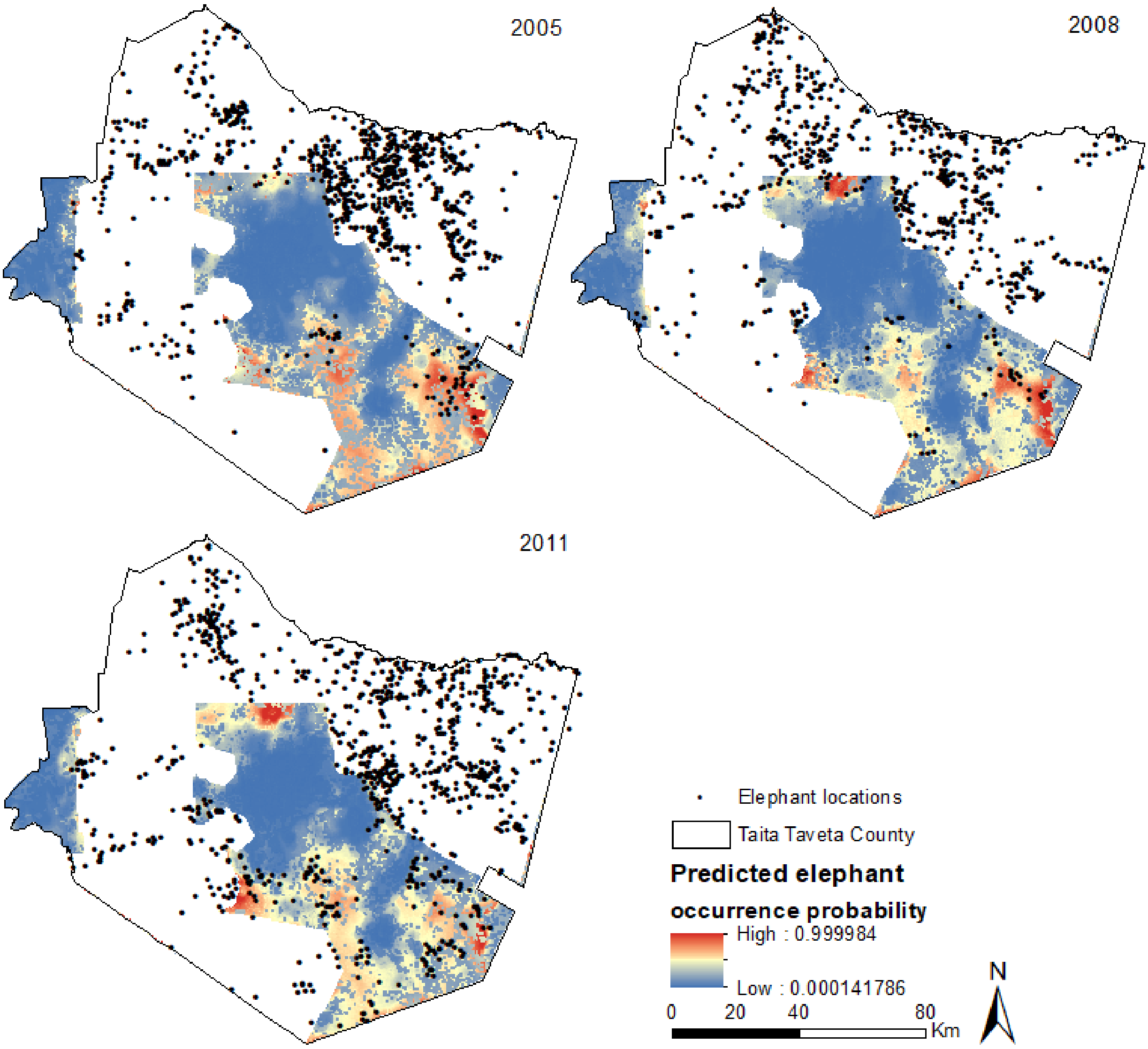


Models trained with 2005 data for the areas outside of protected areas using chosen variables.



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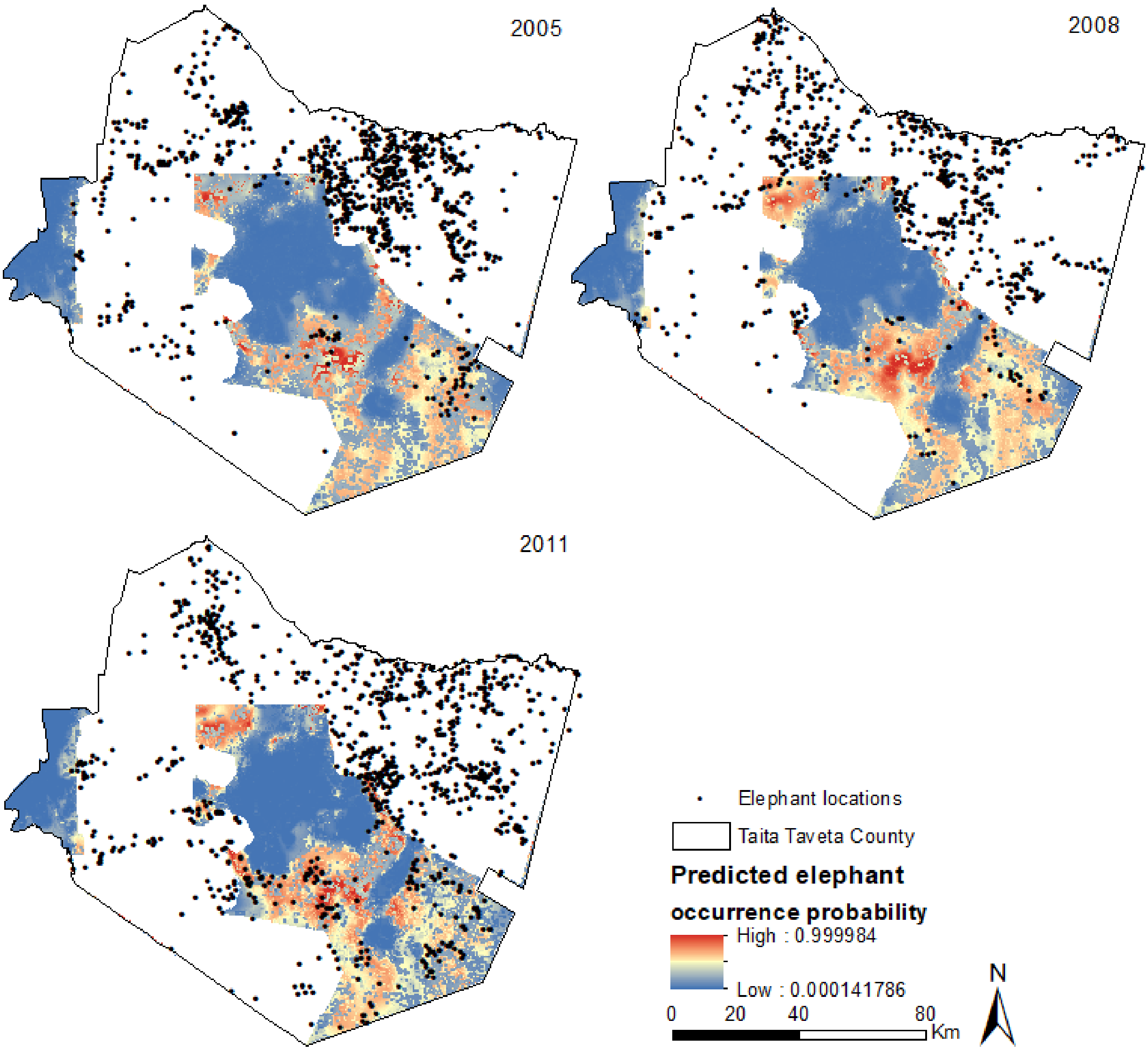

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